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UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 1017
Contribution from the Bureau of Public Roads
THOMAS H. MacDONALD, Chief

Washington, D. C. PROFESSIONAL PAPER March 31, 1922

# REPORT ON DRAINAGE AND PREVENTION OF OVERFLOW IN THE VALLEY OF THE RED RIVER OF THE NORTH

By

P. T. SIMONS, Senior Drainage Engineer
FOREST V. KING, Drainage Engineer

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P. T. Simons, *Senior Drainage Engineer.*
Forest V. King, *Drainage Engineer.*

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## INTRODUCTION.

That a comprehensive drainage program is essential for the proper development of agriculture in the valley of the Red River of the North was recognized soon after farming began to be extensively practiced in that valley, about 1870. In the spring melting snow and rain combined are apt to cause high floods, which delay spring planting, interrupt traffic on roads and railroads, and greatly hamper business. During the summer heavy storms covering relatively small areas often cause floods which do considerable damage. The watershed has an area of nearly 36,000 square miles, of which 8,500 square miles lie within the valley. The initial effort toward a comprehensive drainage plan was made at a convention at Crookston, Minn., in 1886, when it was arranged to prepare plans for draining six Minnesota counties bordering on the Red River.

Drainage in this valley is an interstate matter because outlets are necessary into the Red River, the Bois de Sioux River, and Lake Traverse, which together constitute the boundary between Minnesota and North Dakota, and a part of the boundary between Minnesota and South Dakota. In 1900, as a result of the disastrous 1897 flood in the valley, a tri-State drainage association was formed among property owners and other parties interested in the welfare of the valley; and in 1906 an international drainage conference was held at Grand Forks, N. Dak., which was attended by delegates named by the governors of the three States in which the valley is situated and by delegates from Manitoba, Canada. Various plans for obtaining relief from floods and poor drainage conditions have been studied and much time and money have been expended on them. A list of Federal investigations up to 1915 is contained in House Document No. 1666, Sixty-third Congress, third session. Aside from the Federal investigations, numerous State and local organizations have from time to time taken action under the State laws. Some of the projects have led to considerable legal contention. In addition to the fact that any project affecting this watercourse requires the joint action of the three States involved, the official designation of Lake Traverse and the Red River as navigable waterways makes it necessary that any plans for improvement that might affect the regimen of those waterways shall receive the approval of the Secretary of War.

The attention of the Bureau of Public Roads was first called to the project in August, 1916. In October, 1916, the bureau agreed to make a preliminary examination of the project provided the interested landowners should raise a fund to be used for paying certain incidental expenses. In the summer of 1918 a fund of $2,300 was provided by eight county boards. This fund was raised largely through the efforts of Mr. Herbert A. Hard, of the North Dakota Flood Control Commission.

Field work on the project was begun in September, 1918, and was completed in April, 1920. P. T. Simons, senior drainage engineer, was placed in charge of the project. He was assisted in the field by B. S. Clayton, Dan S. Helmick, and F. V. King, all drainage engineers of the bureau, and by Paul Funderhide, drainage assistant. F. V. King, Guy L. Smith, and W. C. Whitney, drainage engineers, assisted in the preparation of the report.

## SUMMARY OF RECOMMENDATIONS.

The protection of the valley of the Red River of the North from overflow and the securing of adequate drainage for the low-level lands in the valley require the construction of works—to prevent or to control overflow, and to provide an outlet for the drainage of the entire watershed. Two interstate projects are recommended and several State or local projects suggested.

### LAKE TRAVERSE-BOIS DE SIOUX PROJECT.

In the upper portion of the watershed the Lake Traverse-Bois de Sioux project, affecting three States, is proposed to function as follows: (1) By means of a detention reservoir in Lake Traverse run-off would be kept under control, and high-water discharge in the Red

River would be appreciably reduced in that part of the stream above the mouth of the Sheyenne River; (2) by the construction of drainage channels in the territory below the reservoir complete drainage of 112,370 acres of land would be made possible.

The estimated cost of improvements in this project is $1,400,000, approximately $12.50 per acre of land for which drainage outlets would be provided.

### RED RIVER PROJECT.

In the Red River Valley proper, below the junction of the Otter Tail and Bois de Sioux Rivers, the Red River project, affecting two States, is proposed. It would function as follows: As a result of improving the river channel and constructing a flood by-pass channel, the discharge capacity of the stream would be so increased as to lower the high-water stages by 5 feet or more. In order to secure these results at the international boundary it would apparently be necessary to continue the channel improvements for about 30 miles (measured along the river) beyond the boundary. The estimated cost of improvements in this project is $4,000,000, or an average of $8 per acre for 500,000 acres of land on which overflow would be prevented.

The completion of the two projects would render the State boundary streams capable of affording outlet drainage for the entire Red River watershed. Moreover, high-water stages would be reduced by 5 feet or more, so that practically no overflow would occur.

### STATE AND LOCAL PROJECTS.

Serious overflow occurs along the tributary streams on both sides of the Red River and extensive areas need additional local drainage. In planning the above improvements due allowance has been made for the effects of such future local works. No plans nor estimates in detail for projects along the tributaries are submitted because no interstate problems will be involved. A summary of the Red Lake project, as proposed by the Corps of Engineers, United States Army, is, however, included.

### THE RED RIVER VALLEY.

In this report Lake Traverse (see fig. 1) refers to the lake area lying along the State line between Browns Valley, Minn., and White Rock, S. Dak. Bois de Sioux River refers to the watercourse extending from the outlet of Lake Traverse along the State line to Wahpeton, N. Dak. The Red River proper is formed by the junction of the Bois de Sioux River and the Otter Tail River at Wahpeton and extends northward to Lake Winnipeg in the Province of Manitoba, Dominion of Canada. It crosses the international boundary just north of Pembina, N. Dak.

## PHYSICAL CHARACTERISTICS.

Lake Traverse, the Bois de Sioux River, and the Red River form a continuous natural watercourse from Browns Valley, Minn., to the international boundary, a distance of 456 miles. From the outlet of Lake Traverse the stream follows a winding course through the center of a flat valley, the general direction of flow being almost due north (see fig. 1). The fall in general is slight and diminishes toward the north (see fig. 2). The surface altitudes above sea level are: 980 feet at Lake Traverse; 963 feet at Wahpeton; 900 feet at Fargo; 830 feet at Grand Forks; 789 feet at the international boundary; and 755 feet at Winnipeg, 62 miles north of the boundary.

### TOPOGRAPHY.

The watershed of that part of the river above the international boundary has an area of 35,895 square miles (fig. 1). It consists of a broad plain flanked on the east and west by higher land. This central plain has a width of from 15 to 30 miles. To the eye the land appears level but it has a certain degree of natural drainage so that it can in no sense be classed as swamp land. The bordering land rises more or less sharply to the higher parts, which are from 300 to 700 feet above the central portion of the basin.

The eastern part of the watershed originally was forested and contained extensive swamps and many lakes. Much of the timber has been cut and the land cleared, so that at present it is estimated that not more than one-tenth of the whole watershed is forested. Probably 80 per cent of the prairie and cleared lands are now cultivated, the remainder being utilized in raising grasses and for town and building sites, drainage channels, highways, and railroads.

### GEOLOGICAL ORIGIN.

Geologists state that during the glacial period the entire central portion of the valley was covered by glaciers which were deepest near the center of the valley. The glaciers moved toward the south and the water from them flowed to the south. As the glaciers melted and their southern edges receded, a barrier of earth, sand, gravel, and bowlders formed to the south of Lake Traverse. Water from the melting glaciers accumulated behind this barrier and formed a lake that has since disappeared, which the geologists call Lake Agassiz. There was not, however, sufficient water to erode the barrier south of the lake. The glaciers continued to melt away until finally the water in the lake was enabled to drain away to the north into Lake Winnipeg. Water from the melting glaciers, and that which has been flowing off since the glacial period, eroded and formed the channels of the present watercourses.

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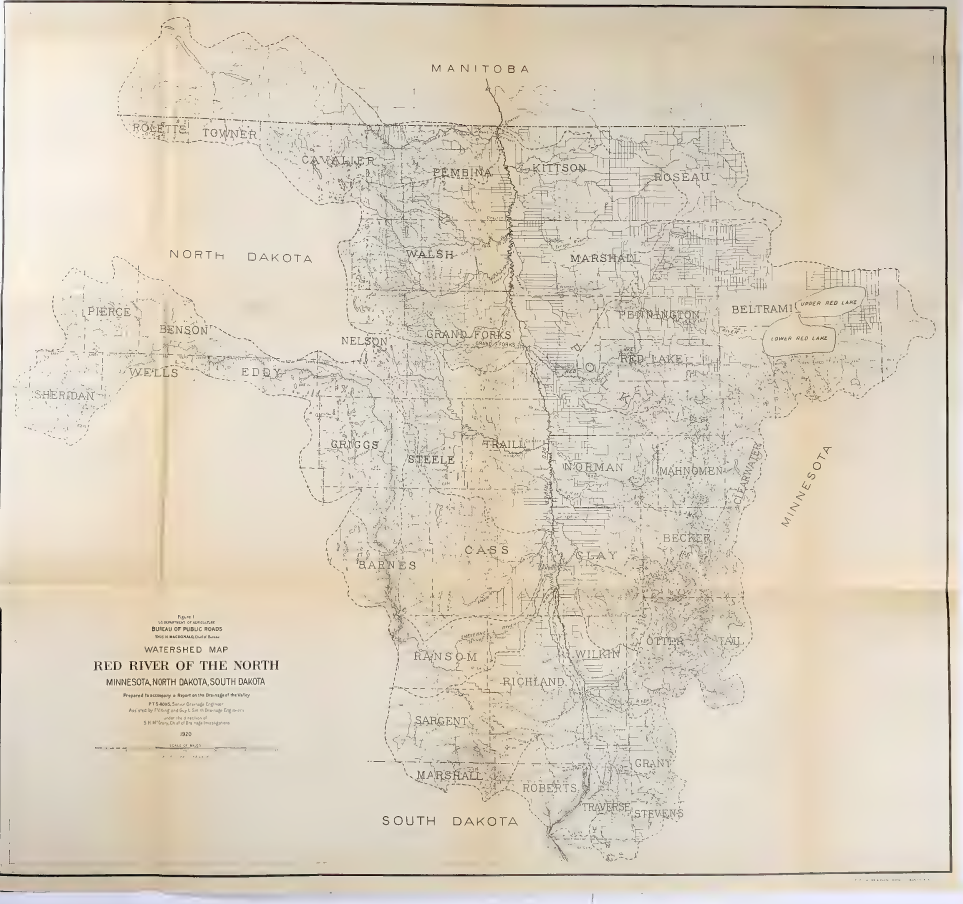

Figure 1

U.S. DEPARTMENT OF AGRICULTURE
**BUREAU OF PUBLIC ROADS**
THOS H. MACDONALD, Chief of Bureau

WATERSHED MAP

# RED RIVER OF THE NORTH

## MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA

Prepared to accompany a Report on the Drainage of the Valley

P. T. SIMONS, Senior Drainage Engineer
Assisted by F. V. King and Guy L. Smith Drainage Engineers
under the direction of
S. H. McCrory, Chief of Drainage Investigations

1920

SCALE OF MILES

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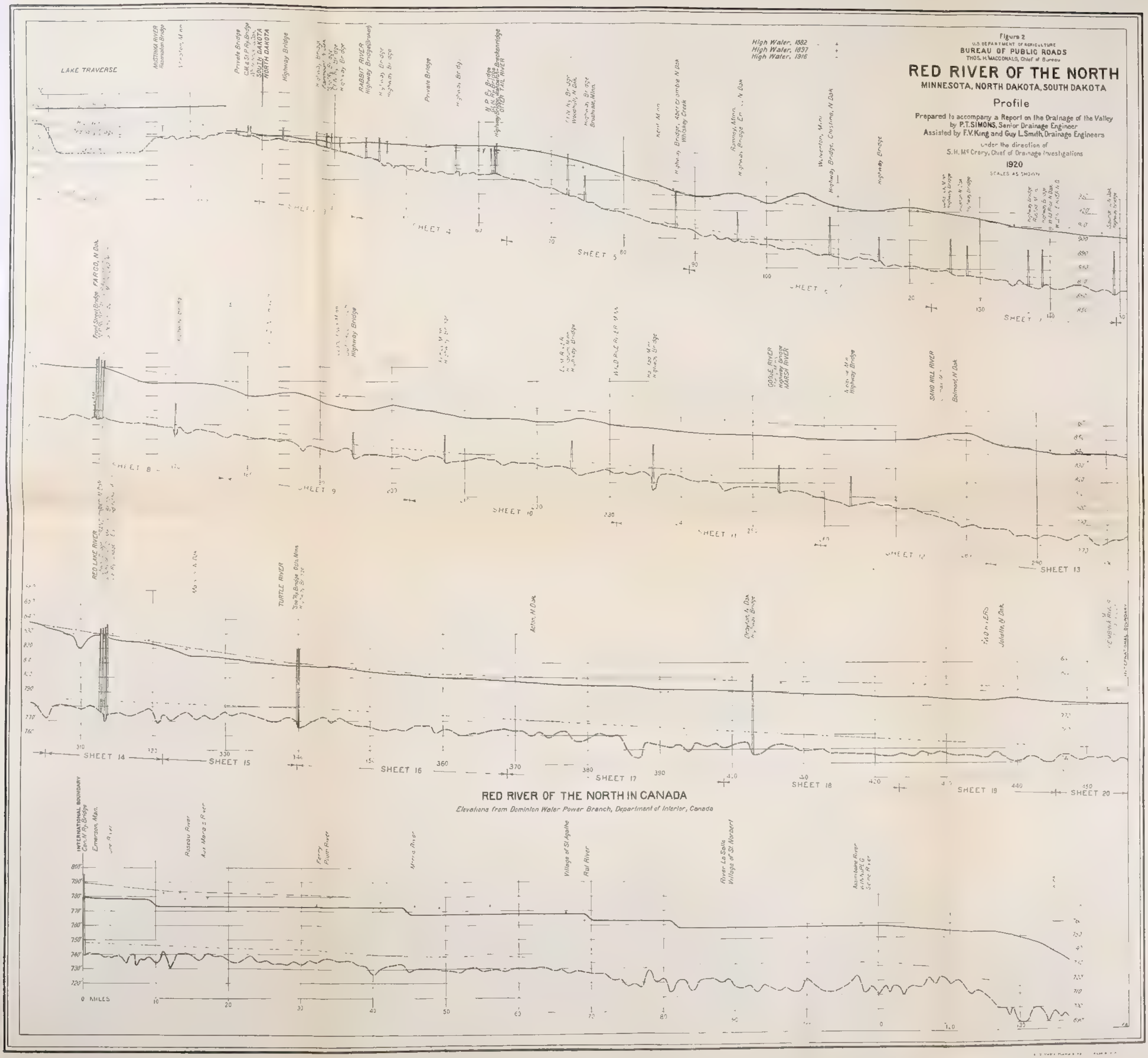

Figure 2

U.S. DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

THOS. H. MACDONALD, Chief of Bureau

## RED RIVER OF THE NORTH

MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA

Profile

Prepared to accompany a Report on the Drainage of the Valley
by P.T. SIMONS, Senior Drainage Engineer
Assisted by F.V. King and Guy L. Smith, Drainage Engineers
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1920

SCALES AS SHOWN

The glaciers eroded the hills that then existed and filled the valleys. Rocks were ground into gravel and sand. As the glaciers receded to the north the materials deposited by them were further reduced by waves and currents in the lake. The streams brought down silt which was deposited in the lake. In this manner were formed the topographical features and the soils now found in the watershed of the Red River.

### SOIL.

The soils throughout the former glacial lake bed are deep, heavy, finely divided, well-compacted mixtures of clay, loam, and small proportions of very fine sand. For the first foot or more this mixture is deeply blackened by decayed organic matter. The soils of the valley are classified by the United States Bureau of Soils (Bulletin 96, 1913) as the Fargo series of soils. Six types are mentioned: Clay loam, fine sandy loam, loam, fine sand, clay, and silt loam comprise the principal areas. In their natural condition most of these soils are poorly drained. All are fertile and, when drained, admirably adapted to agricultural purposes. The soil of the upper levels of the watershed is less uniform in quality and somewhat less productive than that of the central valley, but through drainage, clearing, and proper farming methods practically all can be developed into excellent farm land. Along the edges of the central plain are found moraines and shore lines of the former lake. These are long, low ridges of sand or gravel from a few hundred feet to a half-mile in width. Such land has less agricultural value than any other in the watershed.

### WATERSHEDS.

The watersheds of the Red River and its tributaries are shown in figure 1, and their areas are given in Table 1.

The Red River watershed has been subdivided as indicated on the map and in the table, for the purpose of comparing the precipitation, temperature, topography, soil, vegetation, and natural and artificial drainage of the different portions, as affecting run-off in the valley.

### UTILITY OF THE WATERCOURSES.

Of the various ways in which the Red River and its tributaries prove useful and valuable to the community the more important are the removal of excess water, water supply, sewage disposal, water power, and recreation. Commercial navigation although in earlier days of great importance has decreased until at present it is insignificant. Commercial fishing is carried on to some extent in different parts of the watershed but the industry is of minor importance in the State boundary waters. Irrigation by water drawn from the streams has been considered, but it has been found that where con-

TABLE 1.—*Watershed areas of the Red River of the North and tributaries.*

| Tributary streams. | | | | | | | Red River of the North-Boise de Sioux River-Lake Traverse. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stream. | Station. | Areas of watersheds in square miles. | | | | Increment to main stream. | Areas of watersheds in square miles. | | | | Station. |
| | | South Dakota. | Minnesota. | North Dakota. | Total. | | South Dakota. | Minnesota. | North Dakota. | Total. | |
| Small streams | Mustinka River mouth | 219 | 72 | | 291 | 291 | 219 | 72 | | 291 | Just above mouth of Mustinka. |
| Mustinka River | Wheaton, Minn | | 756 | | 756 | | | | | | |
| Do | Mouth | | 852 | | 852 | 852 | 219 | 924 | | 1,143 | Just below mouth of Mustinka. |
| Small streams | White Rock, S. Dak | 131 | 12 | 49 | 192 | 192 | 350 | 936 | 49 | 1,335 | White Rock, S. Dak. |
| Do | Fairmount, N. Dak | 10 | 45 | 90 | 145 | 145 | 360 | 981 | 139 | 1,480 | Fairmount, N. Dak. |
| Do | Wahpeton, N. Dak | | 364 | 31 | 395 | 395 | 360 | 1,315 | 170 | 1,875 | Wahpeton, just above mouth of Otter Tail. |
| Otter Tail River | Fergus Falls, Minn | | 1,300 | | 1,300 | | | | | | |
| Do | Breckenridge, Minn | | 1,840 | | 1,840 | 1,840 | 360 | 3,185 | 170 | 3,715 | Breckenridge, just below mouth of Otter Tail. |
| Small streams | North Dakota Wild Rice River mouth. | | 375 | 70 | 445 | 445 | 360 | 3,560 | 240 | 4,160 | Just above mouth of North Dakota Wild Rice. |
| North Dakota Wild Rice River. | Lake Tewaukon | 215 | | 410 | 625 | | | | | | |
| Do | Mouth | 310 | | 1,900 | 2,210 | 2,210 | 670 | 3,560 | 2,140 | 6,370 | Just below mouth of North Dakota Wild Rice. |
| Local drains | Fargo-Moorhead | | 40 | 25 | 65 | 65 | 670 | 3,600 | 2,165 | 6,435 | Fargo-Moorhead. |
| Do | Sheyenne River mouth | | 45 | 50 | 95 | 95 | 670 | 3,645 | 2,215 | 6,530 | Just above mouth of Sheyenne. |
| Sheyenne River | Valley City, N. Dak | | | 4,185 | 4,185 | | | | | | |
| Do | Haggart, N. Dak | | | 5,600 | 5,600 | | | | | | |
| Do | Mouth | | | 7,400 | 7,400 | 7,400 | 670 | 3,645 | 9,615 | 13,930 | Just below mouth of Sheyenne. |
| Buffalo River | Georgetown, Minn | | 1,175 | | 1,175 | | | | | | |
| Minnesota Wild Rice River | Twin Valley, Minn | | 835 | | 835 | | | | | | |
| Do | Mouth | | 1,485 | | 1,485 | | | | | | |
| Goose River | do | | | 1,270 | 1,270 | | | | | | |
| Sandhill River | do | | 425 | | 425 | | | | | | |
| Small streams | Sheyenne River to Grand Forks. | | 485 | 1,200 | 1,685 | 6,040 | 670 | 7,215 | 12,085 | 19,970 | Grand Forks, just above mouth of Red Lake River. |
| Red Lake | Outlet of Red Lake | | 1,950 | | 1,950 | | | | | | |
| Thief River | Thief River Falls | | 1,080 | | 1,080 | | | | | | |
| Red Lake River and Thief River. | do | | 3,600 | | 3,600 | | | | | | |
| Clearwater River | Red Lake Falls | | 1,330 | | 1,330 | | | | | | |
| Red Lake River | Crookston, Minn | | 5,320 | | 5,320 | | | | | | |
| Do | East Grand Forks, Minn | | 5,785 | | 5,785 | 5,785 | 670 | 13,000 | 12,085 | 25,755 | Grand Forks, just below mouth of Red Lake River. |
| Turtle River | Mouth | | | 705 | 705 | | | | | | |
| Forest River | do | | | 1,030 | 1,030 | | | | | | |
| Snake River | do | | 760 | | 760 | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Park River | do | | | 885 | 885 | | | | | | |
| Tamarac River | do | | 365 | | 365 | | | | | | |
| Small streams | Grand Forks to Drayton | | 595 | 170 | 765 | 4, 510 | 670 | 14, 720 | 14, 875 | 30, 265 | Drayton, N. Dak. |
| Two Rivers | Hallock, Minn | | 635 | | 635 | | | | | | |
| Do | Mouth | | 975 | | 975 | | | | | | |
| Small streams | Drayton to Emerson, Manitoba, Canada. | | 370 | 420 | 790 | | | | | | |
| Pembina River | Neche, N. Dak | 1, 995 | | 1, 325 | 3, 320 | | | | | | |
| Do | Pembina, N. Dak | 1, 995 | | 1, 870 | [1] 3, 865 | [1] 5, 630 | 670 | 16, 065 | 17, 165 | [1] 35, 895 | International boundary. |

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[1] Includes 1,995 square miles of Canadian territory.

ditions of flow are suited for this purpose there is no need for irrigation.

Under the conditions existing in this valley the most important function of the watercourses is the removal of excess water. This constitutes a combined problem of drainage and flood control which is of vital interest over practically the entire watershed. This problem is discussed later in the report.

The Red River and its tributaries are the source of the water supply for nine cities and towns having a total population of about 69,000. The most important considerations in the use of streams for municipal water supply are the quantity and quality of the water. It is not sufficient that the total amount of water passing through the stream channel during the year be great enough to supply demands; the flow must be so distributed, either naturally or by artificial means, that at no time will it fall below a minimum consistent with safety. To insure a sufficient degree of dilution of impurities and provide for future increased demands, this minimum flow should always be many times greater than the rate at which the water is withdrawn from the stream for use. In populated districts stream water is seldom of such quality that it can safely be used for domestic purposes without treatment. Where the streams furnish the water supply the flow is abundant except at certain points on the Red Lake River where the flow during exceedingly dry seasons becomes so small as to occasion concern over the concentration of impurities. The increase in minimum flow planned for this river as a part of the Red Lake project would improve this condition. In some of the smaller tributaries the dry-season flow is so slight that water supply from this source is impracticable. In most cases the water taken from the streams is passed through filters which remove the greater part of the suspended impurities, and in the upper parts of the streams such treatment is sufficient to render the water fit for use. However, the water of this drainage basin is very "hard," owing to salts leached from the ground, and can be much improved for domestic use by softening through chemical treatment. In the lower parts of the streams where the accumulation of impurities from above is greater, chemical treatment also is necessary especially during low-water periods, to assure absence of organisms dangerous to health. Fargo and Grand Forks are now operating plants for such treatment of the water, and it is probable that, as the cities along the streams grow and become more numerous, chemical treatment will be commonly resorted to.

The streams in the Red River basin are more used as a means of sewage disposal than for water supply. By dilution and by the action of natural purifying agencies, obnoxious and dangerous effects of this contaminating content are eliminated or greatly reduced. Yet when quantities of sewage are poured into streams beyond their ability to dilute and purify, a nuisance and menace is created and artificial means of preventing contamination become necessary. Red River and its tributaries have in the past carried enough water to dilute the sewage discharged into them, and the sewer outlets have been separated widely enough to allow sufficient exposure to the purifying effects of air, sunlight, and bacterial action. Where stream water has been used for municipal water supply, the intakes have been far enough below sewer outlets to allow partial purification, making it more economical to purify the water withdrawn for use than to treat the sewage before its entry into the streams. In a few cases conditions in the streams below sewer outlets have become bad during the summer low-water periods, and some attempts at sewage treatment have been made. Moreover, trouble has been caused at places by water backing up into sewer mains during flood stages. There is no doubt that with increasing population and the growing use of the streams for water supply, sewage treatment will become necessary in most of the sewerage systems. Indeed, inspection of the streams during dry periods indicates that such necessity will not be long delayed.[1]

Owing to the slight fall of the stream bed, the impossibility of storage, the irregularity of flow, and the occurrence of long-continued low-water stages, the Red River is totally unsuited for economical water-power development. Conditions in the tributary streams, on the contrary, favor such development. The rapid fall of 300 to 500 feet by which streams from both sides reach the central valley seems to afford opportunity for considerable power development, yet owing to light precipitation over the western part of the watershed the streams entering from that side lack sufficient flow to develop profitable, continuous power. A few small plants are in operation, but extensive development is prevented by long periods of low flow and lack of yearly precipitation great enough to provide the storage necessary for continuous operation of power plants. It is on the eastern tributary watersheds that most of the power developments are located, and there the greatest possibilities for future development exist. The annual precipitation is much greater than in the western part and more favorably distributed through the year. The streams have consequently a much greater and more uniform flow. Many of the valleys have such slopes that by properly locating dams sufficient water can be stored to provide flow enough throughout the year for the profitable operation of power plants. Power has been developed on the Otter Tail, Minnesota Wild Rice, and Red Lake Rivers, and on certain smaller streams. At present there is in operation over 3,000 horsepower and, according to Chandler's estimate,[2] by utilizing the storage possibilities in the headwaters of the streams a total of between 100,000 and 200,000 horsepower can be developed throughout the year.

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[1] Quarterly Journal of the University of North Dakota, Vol. IX, No. 3, April, 1919. Elwyn F. Chandler.

In the way of recreation the streams and lakes provide swimming, fishing, boating, and skating. The wooded banks of the waterways are well suited for camping. In the cities and towns tracts adjoining the streams have been reserved for public use, and fine parks and playgrounds are numerous throughout the settled districts.

To utilize their various possibilities, it is often necessary to regulate by artificial means the regimen of streams. This has been done in the streams of the Red River watershed in the interest of waterpower and drainage, especially in connection with drainage. The regulation and control of run-off is of more importance in its relation to the development of drainage and flood control in the valley than in connection with any other services which the streams perform. Consequently no changes should be made in the regimen of the waterways, in the interests of the minor services, that would be adverse to the drainage interests.

### WATER TRANSPORTATION.

Water transportation on the Red River was carried on as far south as the junction of the Otter Tail and Bois de Sioux Rivers at Breckenridge. The early traders used the stream as a lane of travel and for the transportation of articles of trade and supplies. When the valley became somewhat settled supplies were hauled by ox team from St. Paul to the river and thence by boat to their destinations. As the country developed, this traffic increased greatly as the river furnished the best means of transport then available up and down the valley. With the coming of railroads and improved facilities for moving freight to and from points on the river a further impetus was given to water transportation; but, with the building of railroads along the river, stream navigation began to decline, and it has gradually fallen off until at present, with railroad lines following the river on both sides for its entire length within the United States, water transportation has practically ceased. The low-water years of 1911 and 1912 stopped commercial navigation of the river, and since then it has not been revived (see House Doc. No. 1666, 63d Cong.).

At and north of Fargo all permanent highway and railroad bridges have been constructed with movable spans over the deepest portion of the channel to accommodate the passage of boats, but since there are no boats on the river the bridges are never opened. Plate I and

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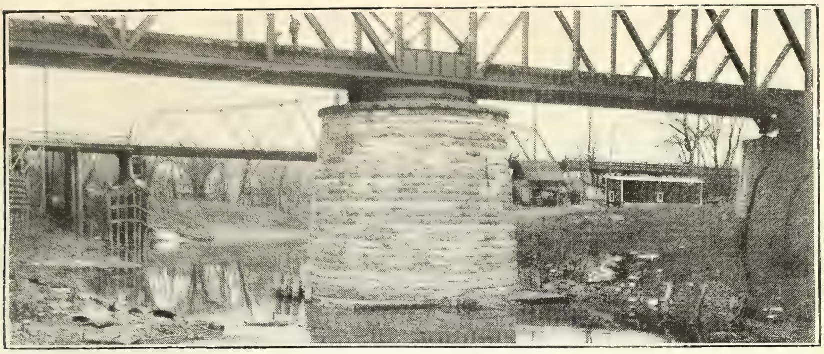
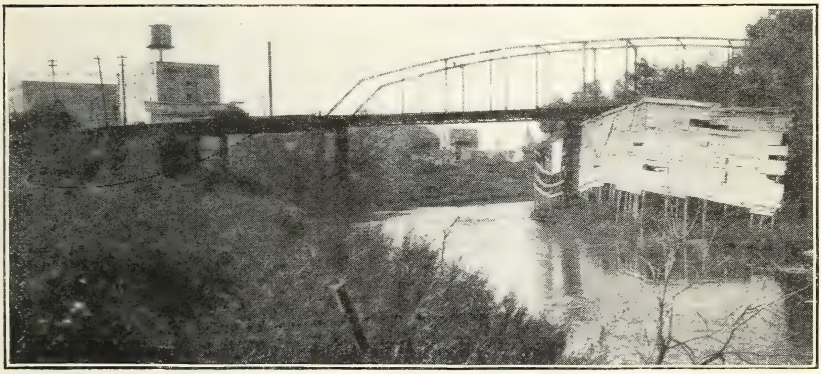
[2] "The Red River of the North," by Elwyn F. Chandler, Quarterly Journal, University of North Dakota, April, 1911.



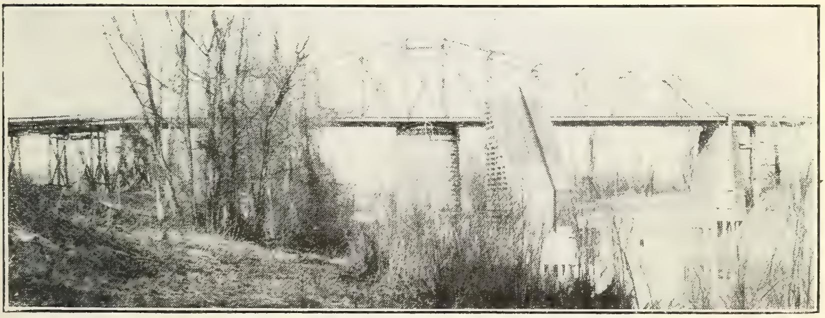
B. P. R.-D-4133

FIG. 1.—LOOKING UP CHANNEL OF THE RED RIVER OF THE NORTH AT NORTHERN PACIFIC RAILWAY BRIDGE BETWEEN MOORHEAD, MINN., AND FARGO, N. DAK., SHOWING LOW STAGE OF WATER DURING THE FALL OF 1910.



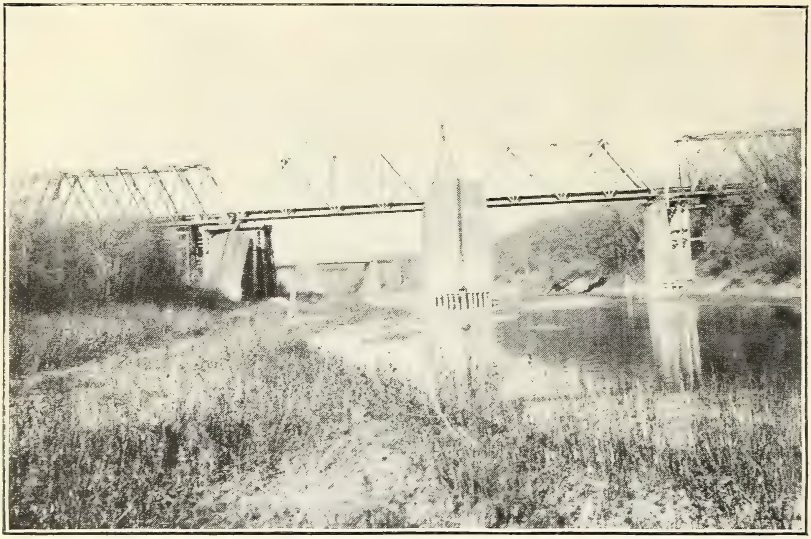
B. P. R.-D-3972

FIG. 2.—LOOKING DOWN THE RED RIVER OF THE NORTH FROM THE NORTHERN PACIFIC AVENUE HIGHWAY BRIDGE, FARGO, N. DAK. NOTE OBSTRUCTION TO FREE FLOW IN CHANNEL BY GUIDE PIER AND TREES. AUGUST, 1919.



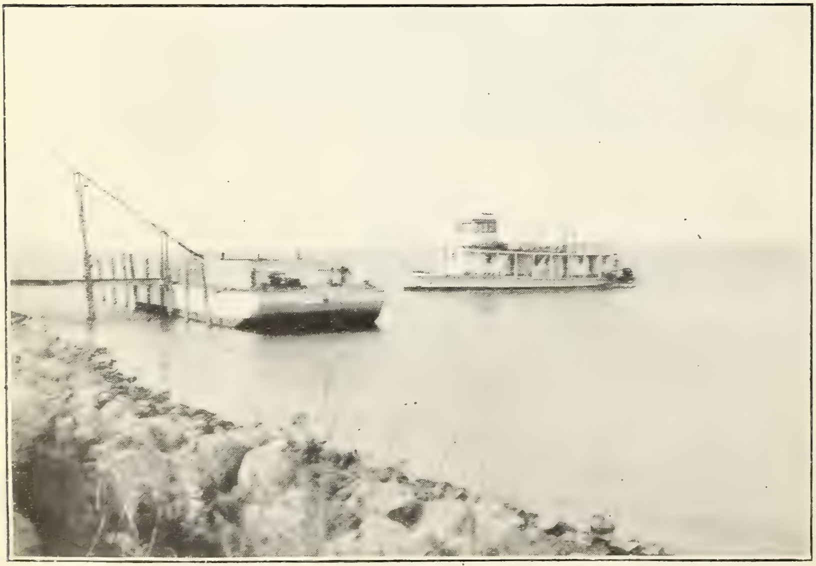
B. P. R.-D-2003

FIG. 3.—LOOKING DOWN THE RED RIVER OF THE NORTH FROM POINT JUST ABOVE MOUTH OF RED LAKE RIVER, GRAND FORKS, N. DAK., NOVEMBER, 1918.



B. P. R.-D-2004

FIG. 1.—LOOKING DOWN RED RIVER OF THE NORTH FROM POINT JUST ABOVE GREAT NORTHERN RAILWAY BRIDGE AT GRAND FORKS, N. DAK., NOVEMBER, 1918. NOTE OBSTRUCTION OF FLOW BY TREES ON BOTH SIDES.



B. P. R.-D-1927

FIG. 2.—SHIPPING GRAIN ON LAKE TRAVERSE AT DIAMOND, S. DAK., IN OCTOBER, 1918.

Plate II, figure 1, show some of the bridges and typical low-water conditions which prevail during several months each year.

The Bois de Sioux River never has been used for water transportation. The fact that it is not a navigable stream is officially stated in the report of a preliminary examination of Traverse and Bigstone Lakes by the Corps of Engineers, United States Army (see House Doc. No. 199, 65th Cong.). Lake Traverse is navigable for a distance of about 12 miles between grain elevators of Diamond, S. Dak., and Browns Valley, Minn., and boats operate between these points (see Pl. II, fig. 2). The only tributary stream on which commercial navigation reached important proportions is Red Lake River, including Red Lake. Transportation on this waterway consisted mainly of log-running and a small amount of freight and passenger service. This traffic decreased with the decline of logging operations and at present has practically ceased.

## SURVEYS AND OTHER INVESTIGATIONS.

The surveys and other investigations by the Bureau of Public Roads were conducted with the constant aim of obtaining as comprehensive an understanding as possible of all factors that now, or that may in the future, affect the drainage and flood situation in the Red River Valley. This necessitated a thorough study of past and probable future precipitation and run-off, and the other influencing factors. Flood conditions were studied with respect to causes, magnitude, extent of damage, probable recurrence, and methods of control and prevention. The possibilities of reclaiming and improving the wet and flood-affected lands were given careful consideration as were also the general efficiency of existing drainage systems and the question of further development of local drainage. Various plans for improving drainage in general and for the control and prevention of floods were studied with a view to selecting the most practicable and advantageous combinations applicable in this watershed. Suggestions in regard to the form of organization best adapted to carrying on the work are made in the following pages.

The measures recommended are of two classes—those the character or design of which is affected by the run-off from territory lying in more than one State, and those designed to remedy evils resulting from local conditions only.

The work in the field was begun in September, 1918, and was continued for practically one year. It was the original intention to make a detailed survey only of the Bois de Sioux-Lake Traverse region, depending on records of former surveys for data concerning the remainder of the valley; but as the work progressed it became apparent that in order to obtain sufficient information to permit an intelligent study of the project, field work would be necessary along the Red River as far north as the international boundary.

## THE RED RIVER SURVEY.

A traverse was run along the Bois de Sioux and Red Rivers from the lower end of Lake Traverse to the international boundary, a distance of about 435 miles. This traverse was tied in to section and township corners at all township lines. South of Wahpeton the lines were run by needle, while north of Wahpeton azimuth was used. The traverse was tied to the range lines. As accurate maps of Lake Traverse and surrounding areas were available, a survey of that part of the valley was not necessary.

## LEVELS.

All elevations are referred to mean sea level, the survey having been based upon bench mark elevations as determined by the United States Coast and Geodetic Survey in the 1912 adjustment. Ties were taken to permanent bench marks set by the Coast and Geodetic Survey and the Geological Survey at various points in the valley, the elevations of which are given in Table 2.

TABLE 2.—*Permanent bench marks used in Red River survey.*

(U. S. Coast and Geodetic Survey datum, 1912 adjustment.)

| Authority. | Reference. | Location. | Description. | Elevation. |
|---|---|---|---|---|
| U. S. G. S. | U. S. G. S. Bull. 643. | White Rock, S. Dak. | At front doorway of store of S. E. Oscarson, in top surface of sandstone step; bronze tablet. | 975.992 |
| Do. | U. S. G. S. Bulls. 469 and 560. | Wahpeton, N. Dak. | Southeast corner of courthouse yard; iron post, stamped "964W." | 963.495 |
| U. S. C. & G. S. | U. S. G. S. Bull. 560. | Glyndon, Minn. | About 1 mile south of Glyndon, 11 telegraph poles south of milepost 18, at southwest corner of grade crossing, 4 meters south of a telegraph pole and in range with the poles; bottom of hole in concrete post (C. & G. S. b. m. V 4). | 923.889 |
| U. S. D. A. | | Fargo, N. Dak. | Agricultural College administration building, lowest section of red sandstone coping, on west balustrade at main entrance; bench mark is 6.4 feet below doorsill and 2.6 feet above surface of ground. Cross cut in center of coping. | 902.65 |
| U. S. C. & G. S. | U. S. G. S. Bull. 560. | Hadler, Minn. | 4 telegraph poles south of sign board, 3 meters south of milepost 53, in range with telegraph poles, 12 meters west of track; top of copper bolt (C. & G. S. b. m. J5). | 900.401 |
| Do. | Letter. | East Grand Forks, Minn. | Near the southwest corner of the southeast footing of the city steel water tank, across the street from the Great Northern Station. A ⅜-inch copper bolt set in lead or cement and flush with a horizontal or vertical surface. | 833.689 |
| Do. | do. | Grand Forks, N. Dak. | 8 inches north of the southwest corner of the post-office building, in the granite foundation wall, 1.3 meters above the ground. A 3-inch red metal disk. | 834.913 |
| U. S. D. A. | | Pembina, N. Dak. | West bank of Pembina River north of road leading to ferry, in yard of Sheriff Atkinson; U. S. G. S. iron bench mark post. | 790.45 |
| Can. Geod. Survey. | Geod. Survey of Canada, Vol. I, No. 3, 1913. | Emerson, Manitoba. | In second course of stonework above ground in east wall of Emerson Post Office, 3 feet from south east corner of building. | 787.361 |

The elevations of the United States Coast and Geodetic Survey bench marks are the result of the latest (1912) adjustment of the precise leveling done by that survey in 1906. At that time the elevations of some of the United States Geological Survey bench marks were redetermined by this precise leveling and the others in the vicinity were adjusted to agree. Since then, the leveling of the Geological Survey in the valley has been based upon the Coast and Geodetic Survey elevations, so that at the present time the elevations of all bench marks of both surveys, as used in this investigation, accord with the latest adjustment of the precise leveling results.

Most of the leveling was done with wye levels. A small part along the Bois de Sioux was done with transits. All levels were required to check within the usual limits of error for wye level work. Base-level lines were run for the entire length of the Bois de Sioux and Red Rivers within the United States, and elevations at frequent intervals were taken of the river bed and banks. From the site of the proposed detention dam northward as far as Wahpeton all land that is affected by floods was covered by the level parties, elevations for the most part being taken along section lines. These areas are shown on sheets 2, 3, and 4, figure 3. Over the remainder of the valley the leveling was confined to the immediate vicinity of the river channel and to ties to various bench marks and points of former surveys.

### CROSS SECTIONS.

Cross sections of the Bois de Sioux and Red Rivers were taken along the whole length at intervals of approximately one mile, and at all bridges (see fig. 4). The valley was cross-sectioned at the sites of the proposed levee at Browns Valley and the detention dam near White Rock. Test borings were also made at the latter point. A few cross sections of the Otter Tail, North Dakota Wild Rice, Sheyenne, and Red Lake Rivers were taken.

### HIGH-WATER DATA.

Special effort was made to locate all reliable high-water marks, both those left by the water or ice on trees, bridges, etc., and those which were set by observers as permanent records. The field parties were constantly on the lookout for reliable information as to high water and from time to time special field trips were made by engineers for this purpose. The elevations of all authentic high-water marks found were taken, and are shown on figure 3, sheets 1 to 20.

### STREAM GAUGING.

Staff stream gauges were established at Haggart and Valley City, N. Dak., on the Sheyenne River; at Wild Rice, N. Dak., on the Dakota Wild Rice; and near Fairmount, N. Dak., on the Bois de

Sioux. Records at these stations were kept and were filed with those available from stations previously established. At Haggart the gauge was adjusted to the same datum as that of the United States Geological Survey gauge for which records are available from 1902 to 1906. The stream flows at these gauges were measured by means of Price current-meter determinations during the summer of 1919, and in addition measurements were made at the Fairmount and Wild Rice gauges during the spring high water in 1920. Ratings during high-water stages were obtained at Valley City and Haggart on the Sheyenne River during the spring of 1919.

### INSPECTION.

Much information was gathered from many sources from field trips to the various parts of the watershed. Especial attention was given the Bois de Sioux and Red Rivers with respect to channel conditions, bridges, high-water marks and flood effects. The camera was freely used in recording conditions bearing on the project. The drainage and flood situations in general were discussed with well-informed residents. Inquiries were made of engineers, farmers, and other interested persons as to the effectiveness of existing drainage systems, the defects in design and construction, the need for additional drainage and the general sentiment regarding its development. Ditch systems were inspected and investigated as to efficiency, state of preservation, completeness of development, and provision for maintenance. Locations which seemed to offer opportunity for reservoir storage were visited and examinations made as to the practicability of their development. Many maps, old photographs, newspapers, historical docouments, and records of various kinds were collected and filed for use in the preparation of this report.

### PROGRESS REPORT.

At the request of parties especially interested in the Lake Traverse-Bois de Sioux region, a progress report was prepared and distributed in February, 1920, setting forth the results of the study of that part of the project and the conclusions drawn as to advisable measures for relief in that territory. All essential information contained in the progress report is included in this report.

### SOURCES OF INFORMATION.

In addition to the data obtained first hand in the field, information of great value was obtained from many sources. In preparing the maps free use was made of such existing maps as would add to the completeness and accuracy of the work. Information concerning past high-water stages and floods was secured from such sources as histories of the early settlement of the country; various reports and papers by early settlers, traders, and explorers; and photographs and old newspaper accounts of floods. The investigation of drainage development was aided by maps and records of the States, counties, and districts prosecuting such projects. Records and maps compiled by the various agencies of the Federal Government furnished valuable data concerning precipitation, run-off, temperature, geography, and geology.

### MAPS AND PROFILES.

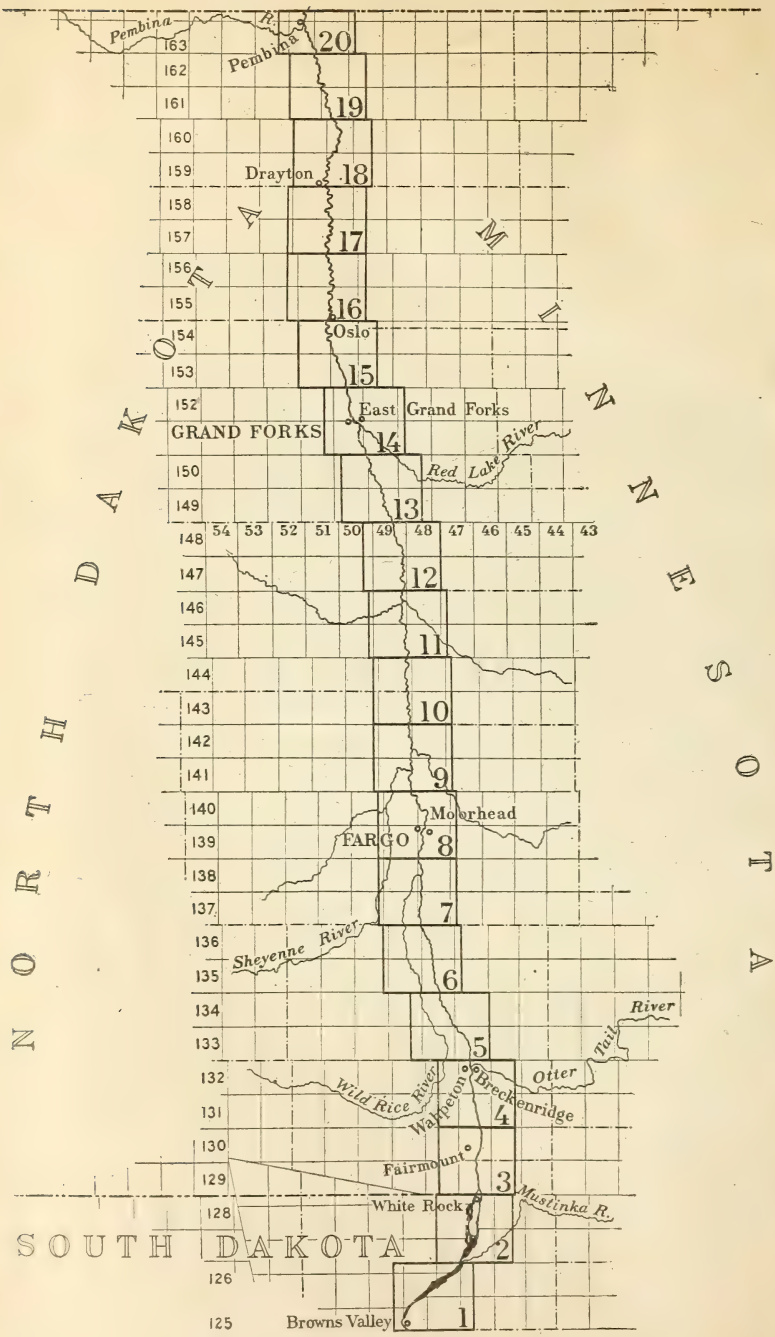
The detail map (fig. 3, sheets 1 to 20) was made up as far as possible from data taken in the field, but as the field work was for the most part done along the main watercourse it was necessary to depend on other maps for information concerning backlying areas. The portions of the map (fig. 3) based on the surveys represent true conditions perhaps more accurately than do the other portions. Features of the map not determined by survey were taken from the best maps available, the data being carefully coordinated and adjusted.

The surface elevations shown are considered equal in accuracy to the general leveling along the river, with the exception of those a mile or more back from the river on the east side from Breckenridge, Minn., to the north line of Marshall County. While these latter elevations are as nearly correct as could be determined from the available data and are considered satisfactory for the purpose of this investigation, there is some doubt as to the degree of accuracy, and they should not be used in preparing plans for local drainage projects without being carefully checked. The General Land Office and Geological Survey plats were freely used in connection with notes of the survey work. War Department maps of Lake Traverse furnished considerable data in that vicinity. For territory not covered by Federal Government agencies, State, county, railroad, and various other maps were used. The locations of artificial drainage systems were supplied from local drainage plats, county and State maps, and drainage district records. Surface elevations, in addition to those taken directly in the field, were obtained from the Geological Survey maps and from ties to other surveys of which plats showing surface elevations were available.

A profile of the watercourse showing stream-bed and bank elevations, bridges, high-water marks, etc., was drawn, and selected cross sections of the river were plotted. The profile and cross sections (figs. 2 and 4) were prepared from data obtained in the field.

### PRECIPITATION AND RUN-OFF RECORDS.

An extended study was made of precipitation records with the view of determining past and probable future intensity and distribution of precipitation as factors influencing run-off. The results



Index map to figure 3.

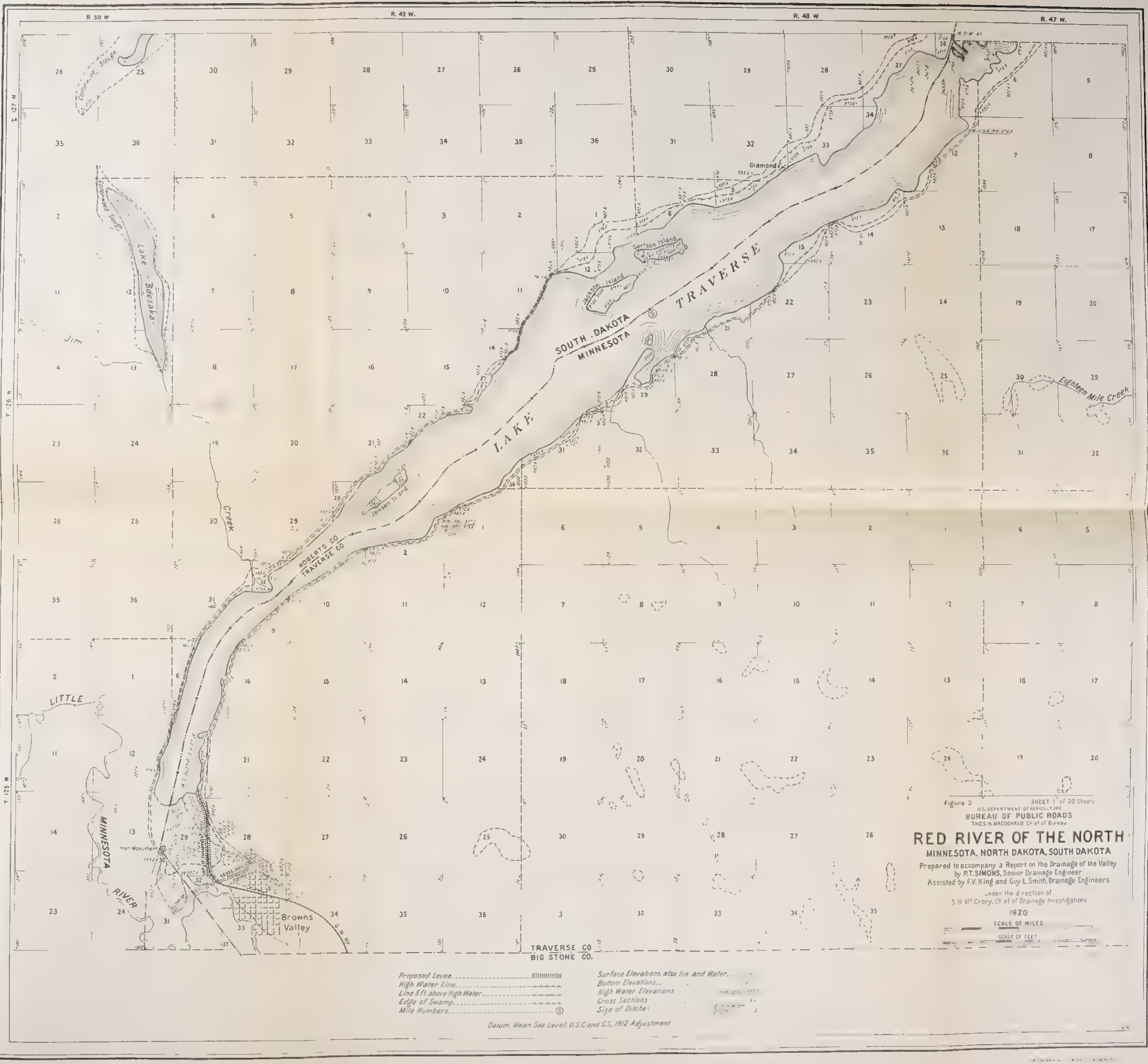


Figure 3 SHEET 1 of 20 Sheets

U.S. DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
THOS. H. MACDONALD, Chief of Bureau

## RED RIVER OF THE NORTH

MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA

Prepared to accompany a Report on the Drainage of the Valley
by P. T. SIMONS, Senior Drainage Engineer
Assisted by F. V. King and Guy L. Smith, Drainage Engineers

under the direction of
S. H. McCrory, Chief of Drainage Investigations

1920

SCALE OF MILES

SCALE OF FEET

Proposed Levee
High Water Line
Line 5 ft. above High Water
Edge of Swamp
Mile Numbers ③

Surface Elevations, also Ice and Water
Bottom Elevations
High Water Elevations
Cross Sections
Size of Ditches

Datum, Mean Sea Level, U.S.C. and G.S., 1912 Adjustment

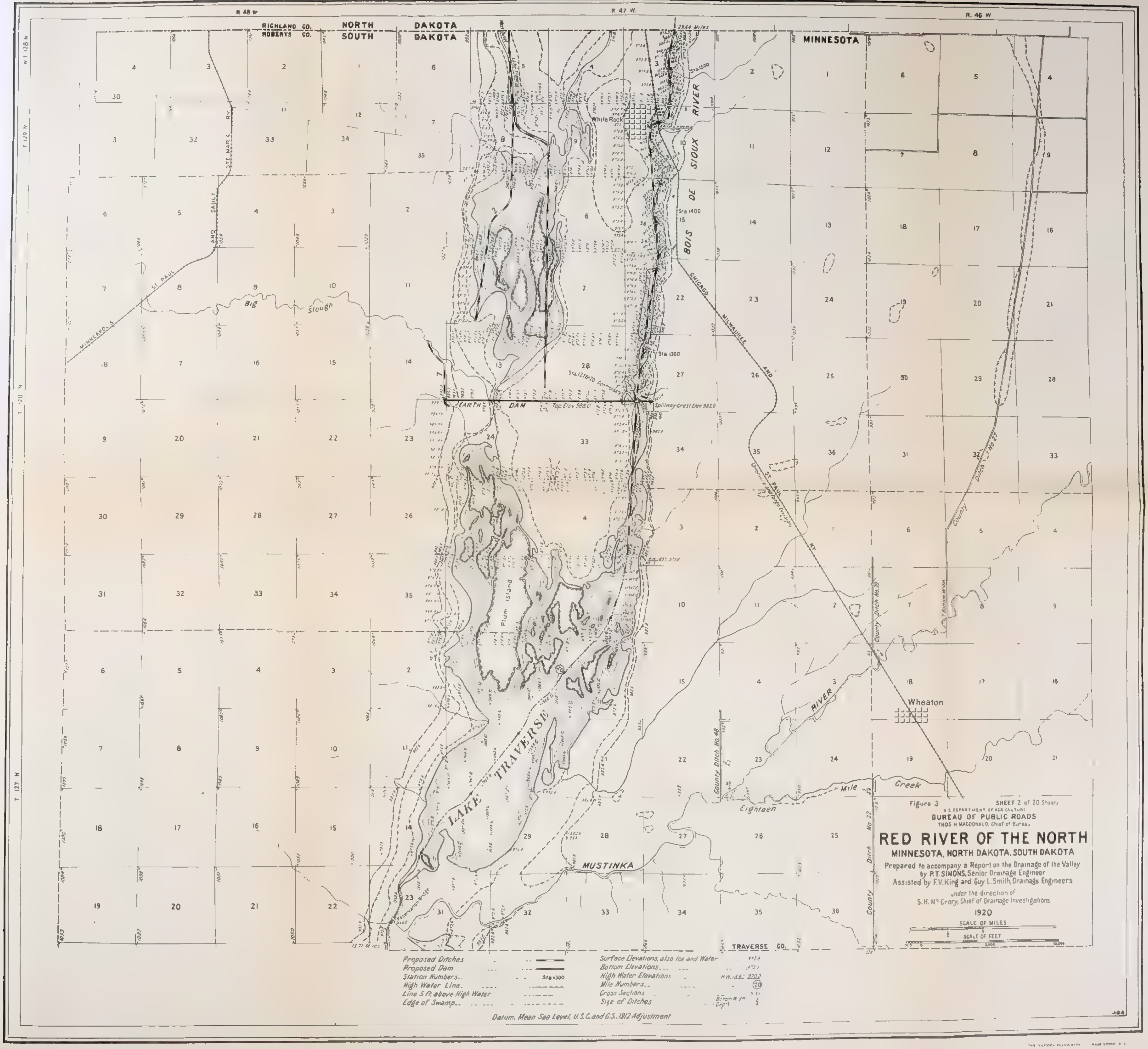


Figure 3

SHEET 2 of 20 Sheets

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SCALE OF MILES

SCALE OF FEET

Proposed Ditches
Proposed Dam
Station Numbers .. Sta 1300
High Water Line
Line 5 ft. above High Water
Edge of Swamp
Surface Elevations, also Ice and Water
Bottom Elevations
High Water Elevations
Mile Numbers .. ⑳
Cross Sections
Size of Ditches .. Bottom Width / Depth

Datum, Mean Sea Level, U.S.C. and G.S., 1912 Adjustment

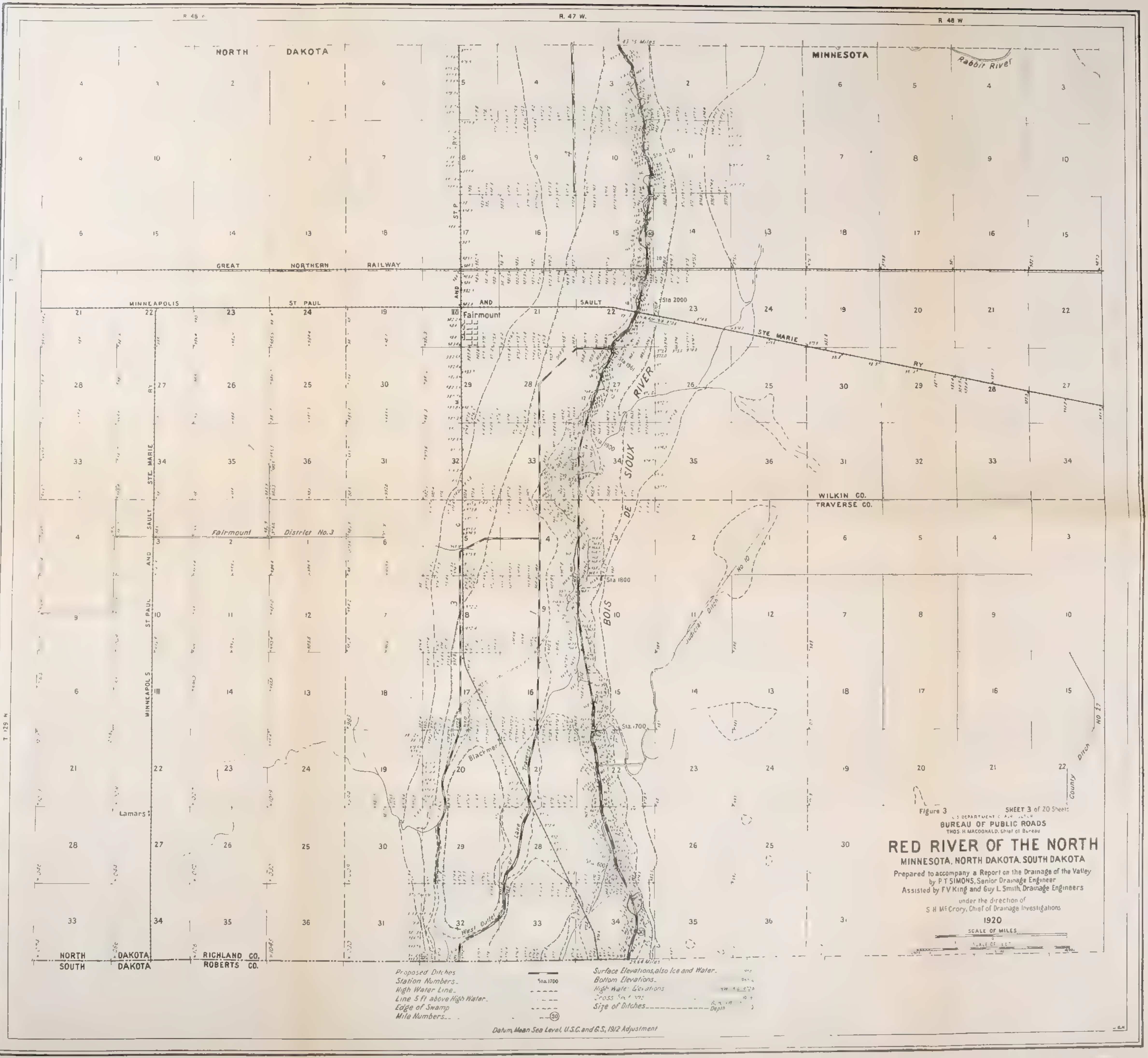

Figure 3

SHEET 3 of 20 Sheets

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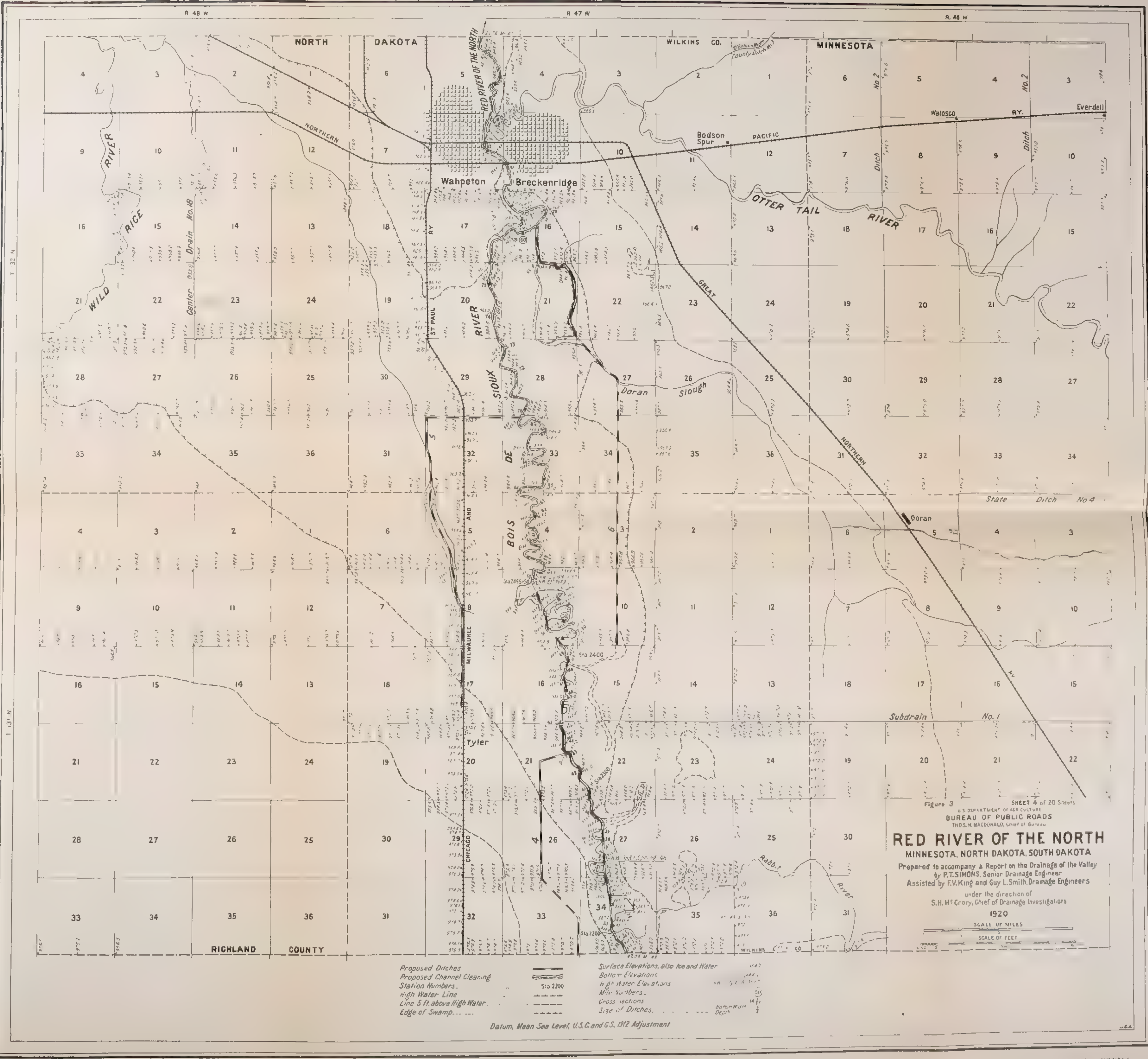

Figure 3

SHEET 4 of 20 Sheets

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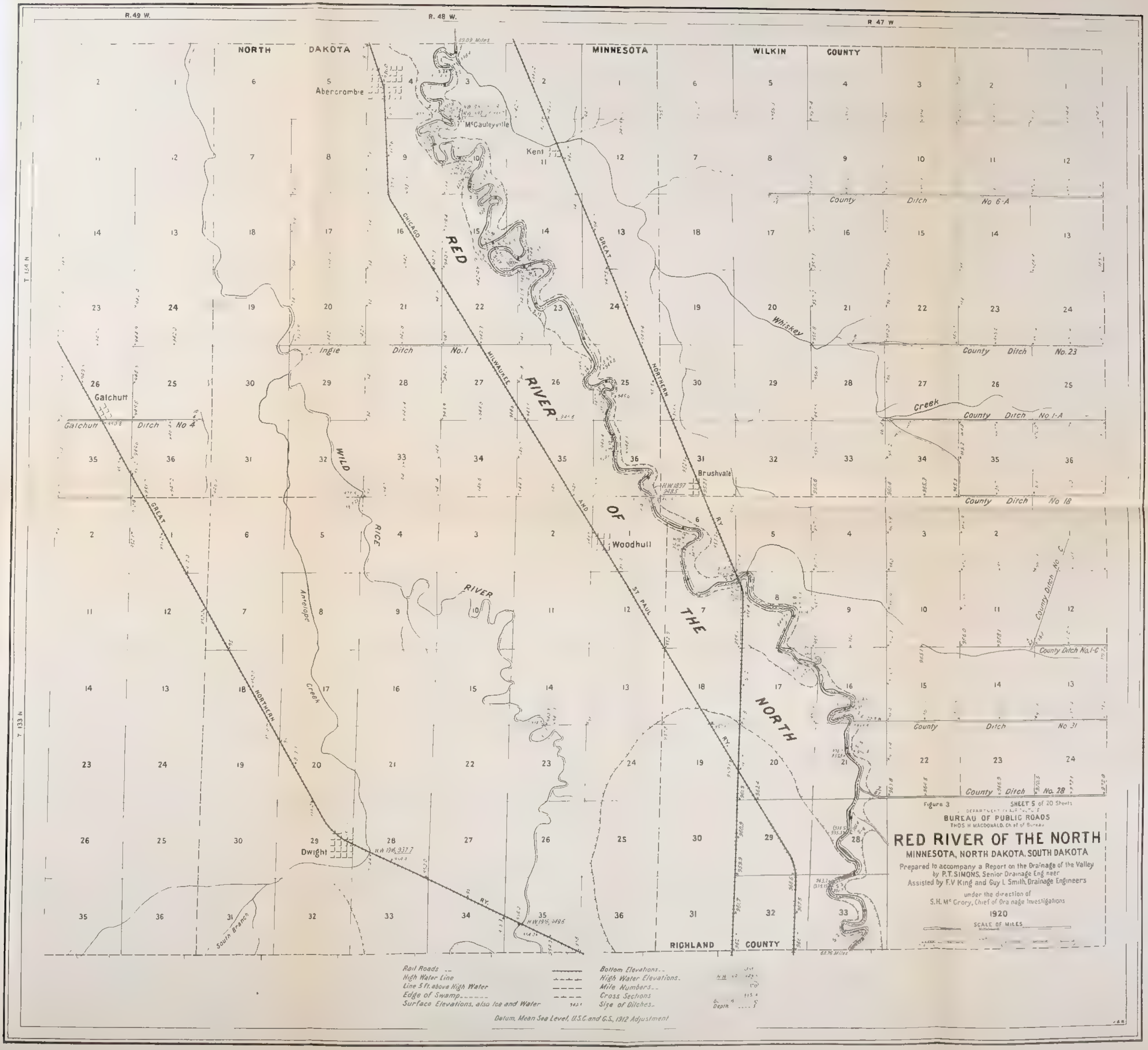

Figure 3

SHEET 5 of 20 Sheets

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SCALE OF MILES

Rail Roads
High Water Line
Line 5 ft. above High Water
Edge of Swamp
Surface Elevations, also Ice and Water
Bottom Elevations
High Water Elevations
Mile Numbers
Cross Sections
Size of Ditches

Datum, Mean Sea Level, U.S.C. and G.S., 1912 Adjustment

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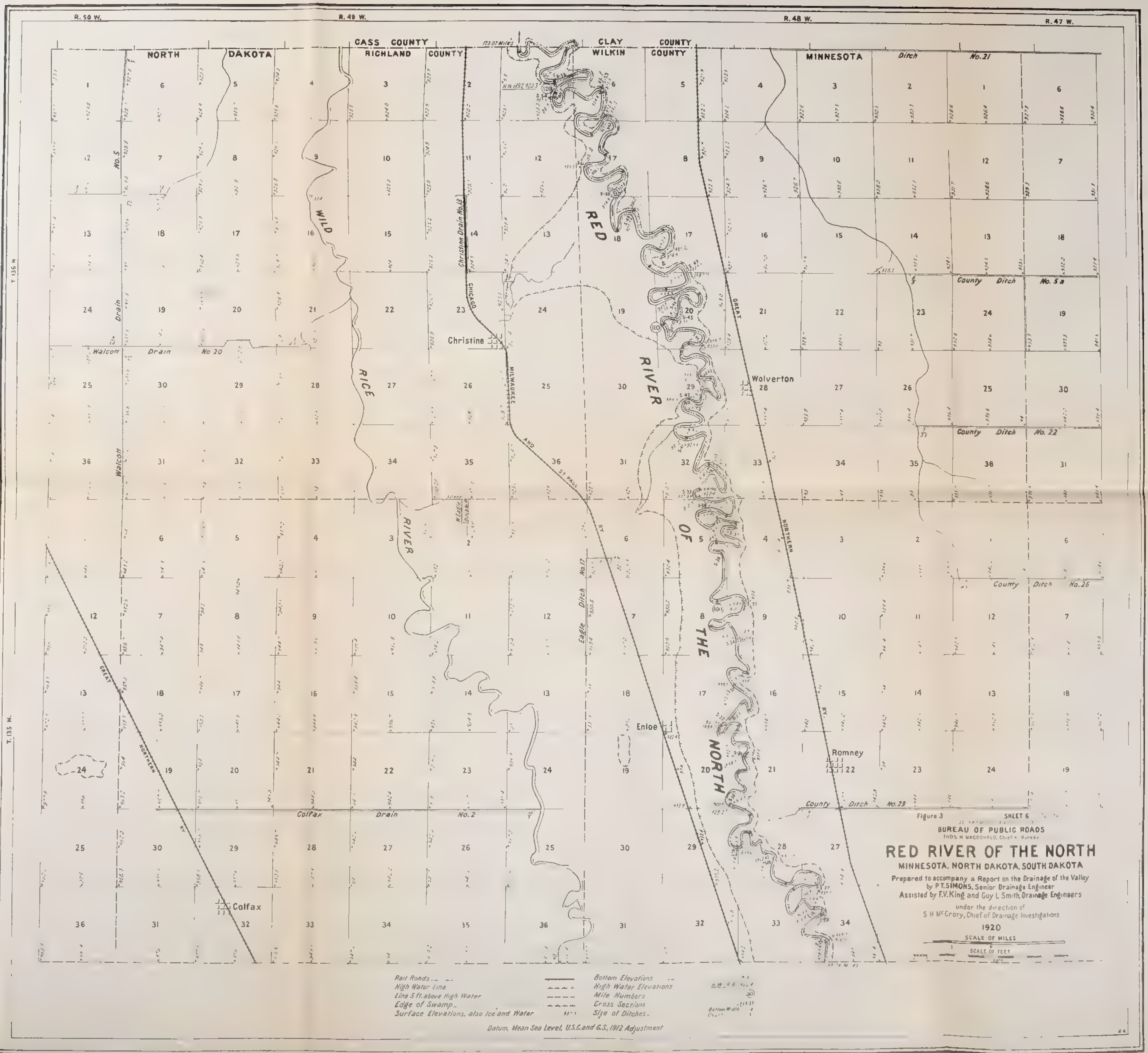

Figure 3

SHEET 6

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RED RIVER OF THE NORTH
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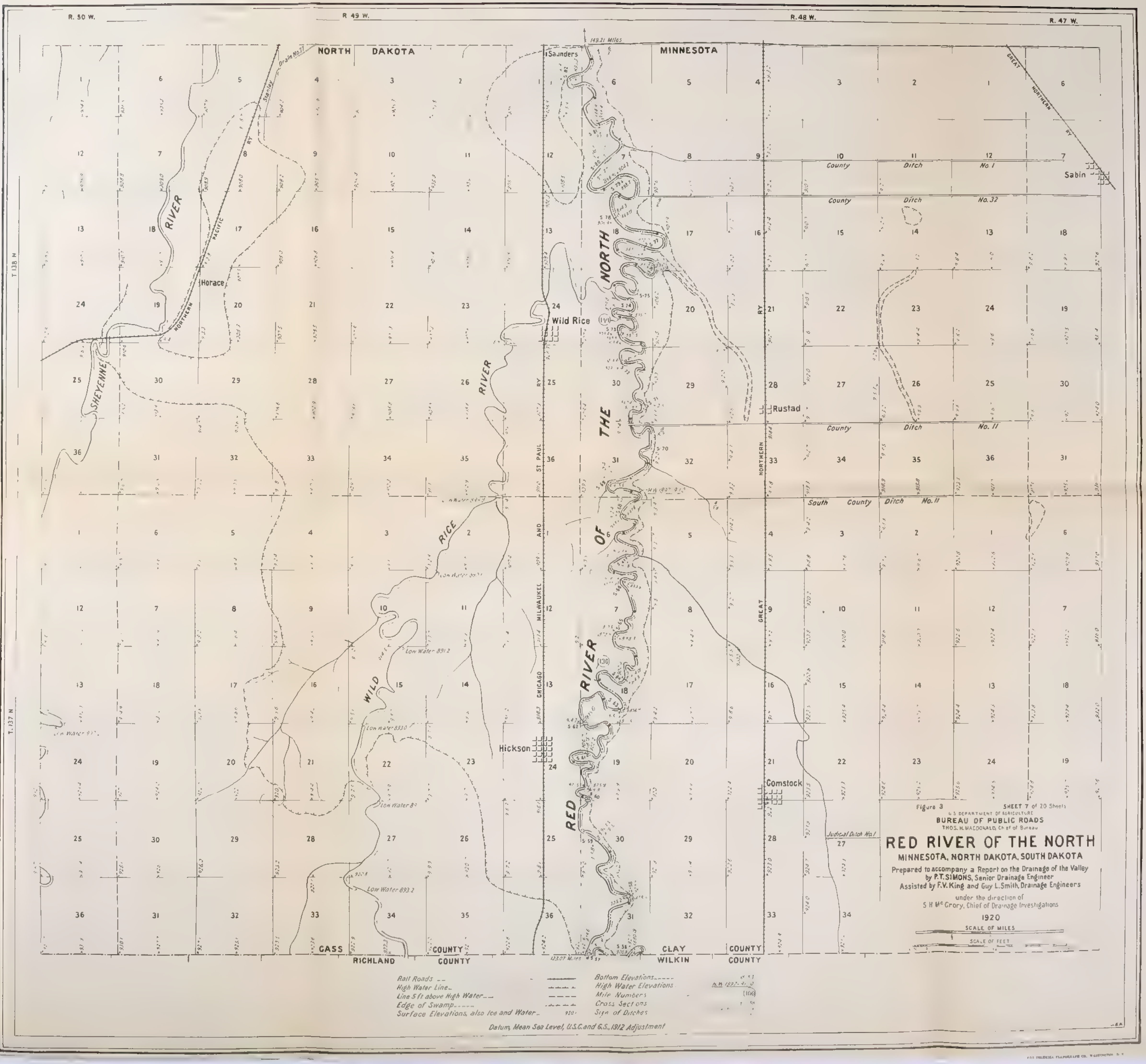

Figure 3

SHEET 7 of 20 Sheets

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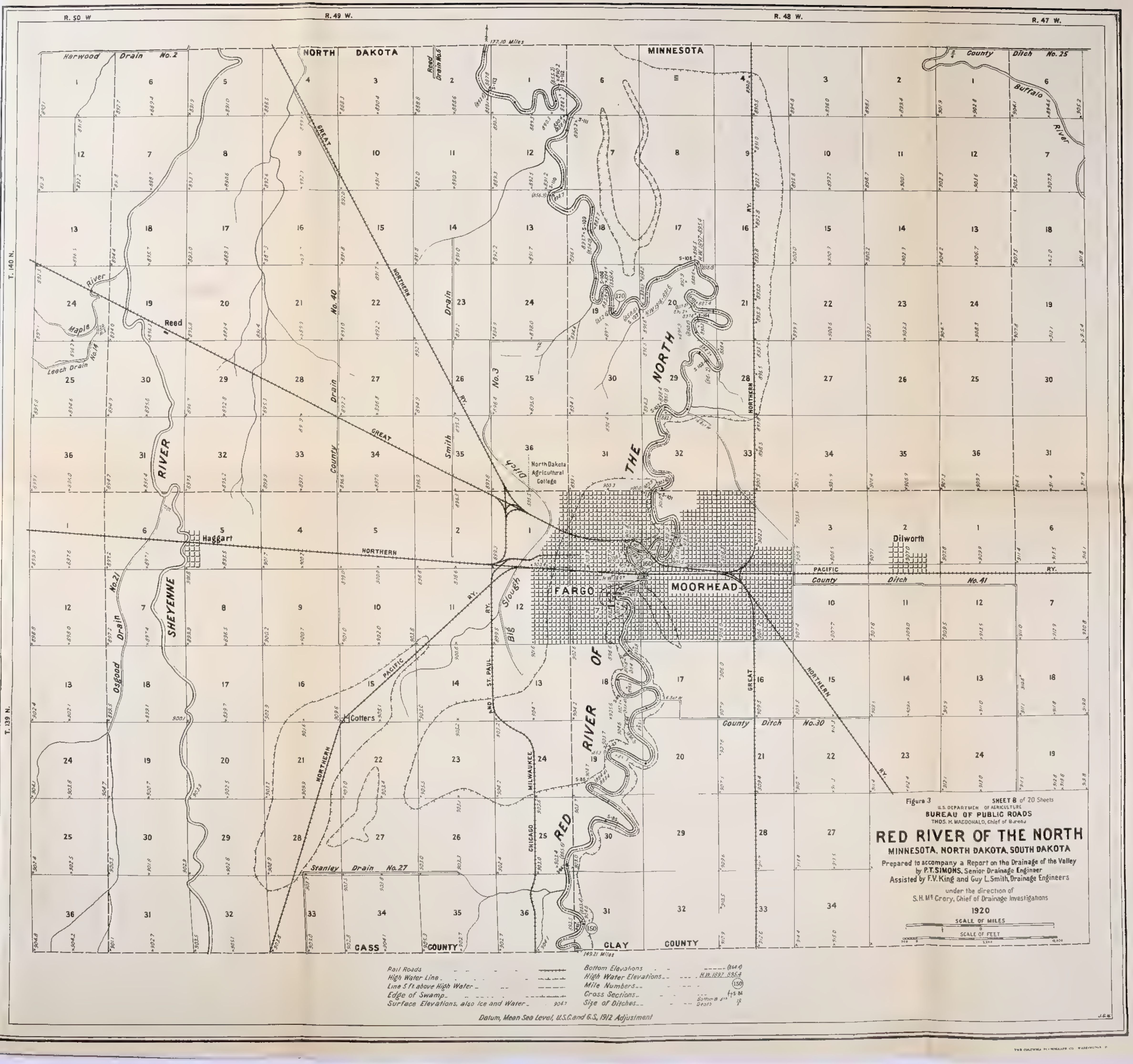

Figure 3

SHEET 8 of 20 Sheets

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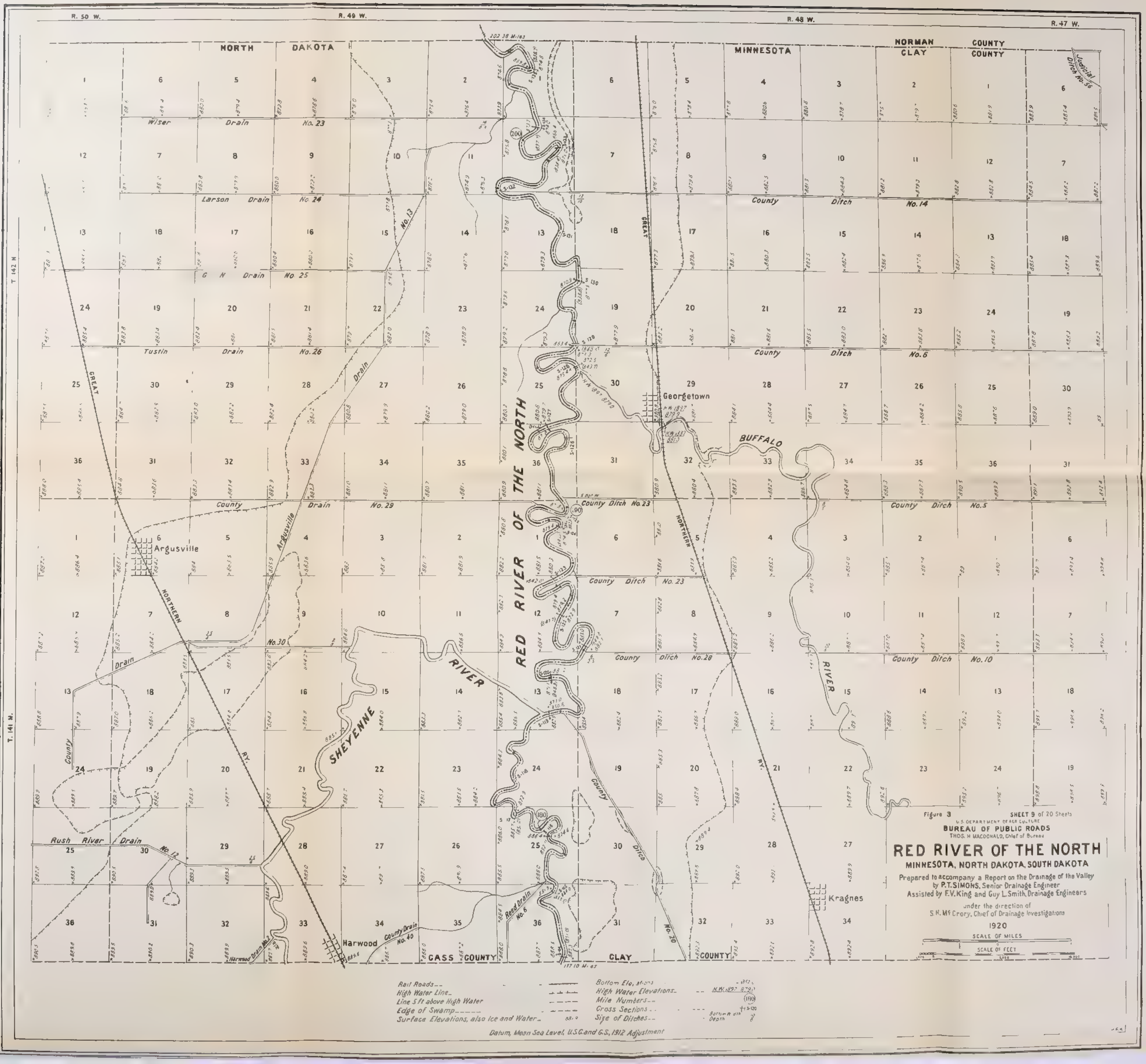

Figure 3

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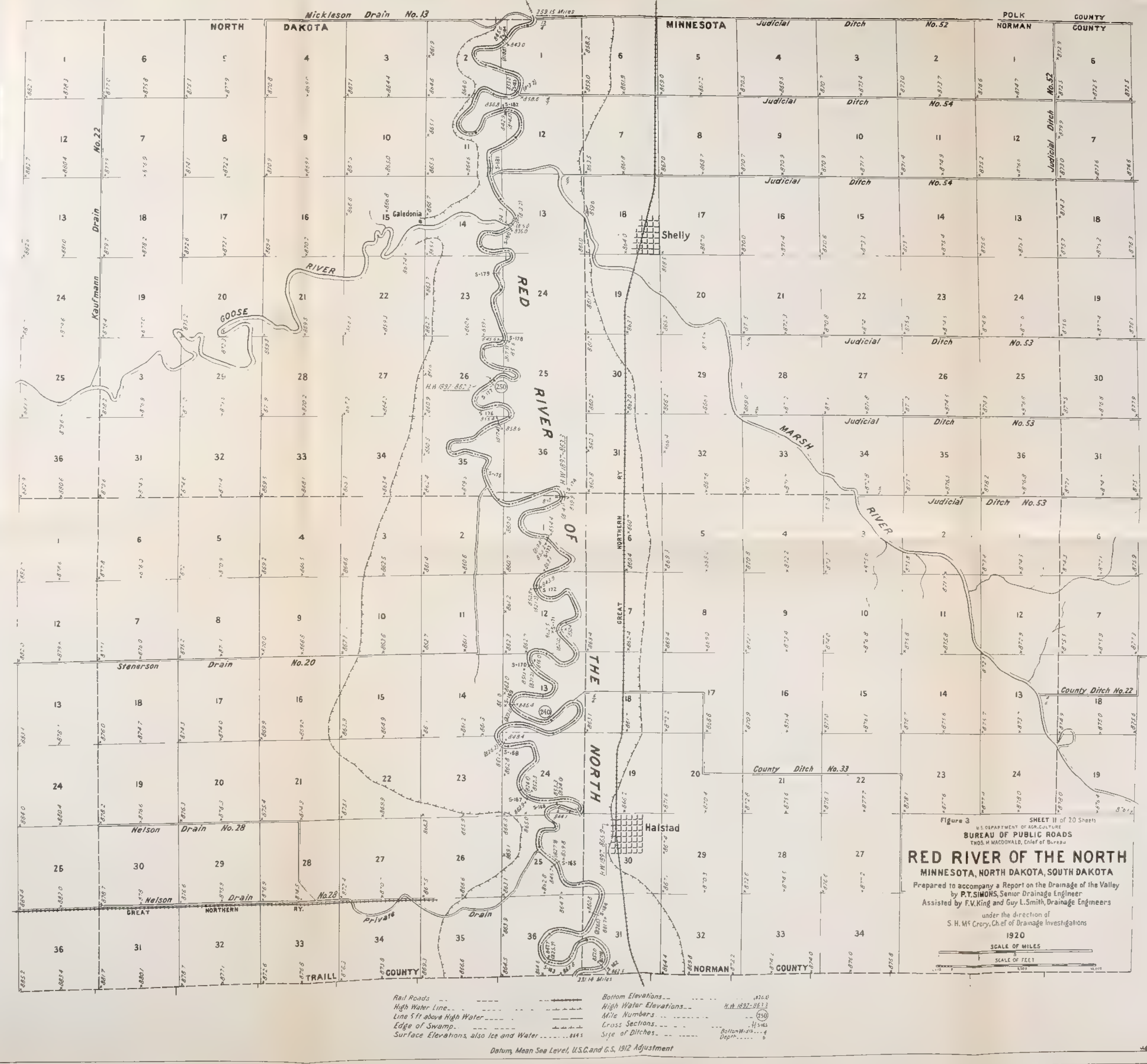

Figure 3

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SCALE OF MILES

SCALE OF FEET

Datum, Mean Sea Level, U.S.C. and G.S. 1912 Adjustment

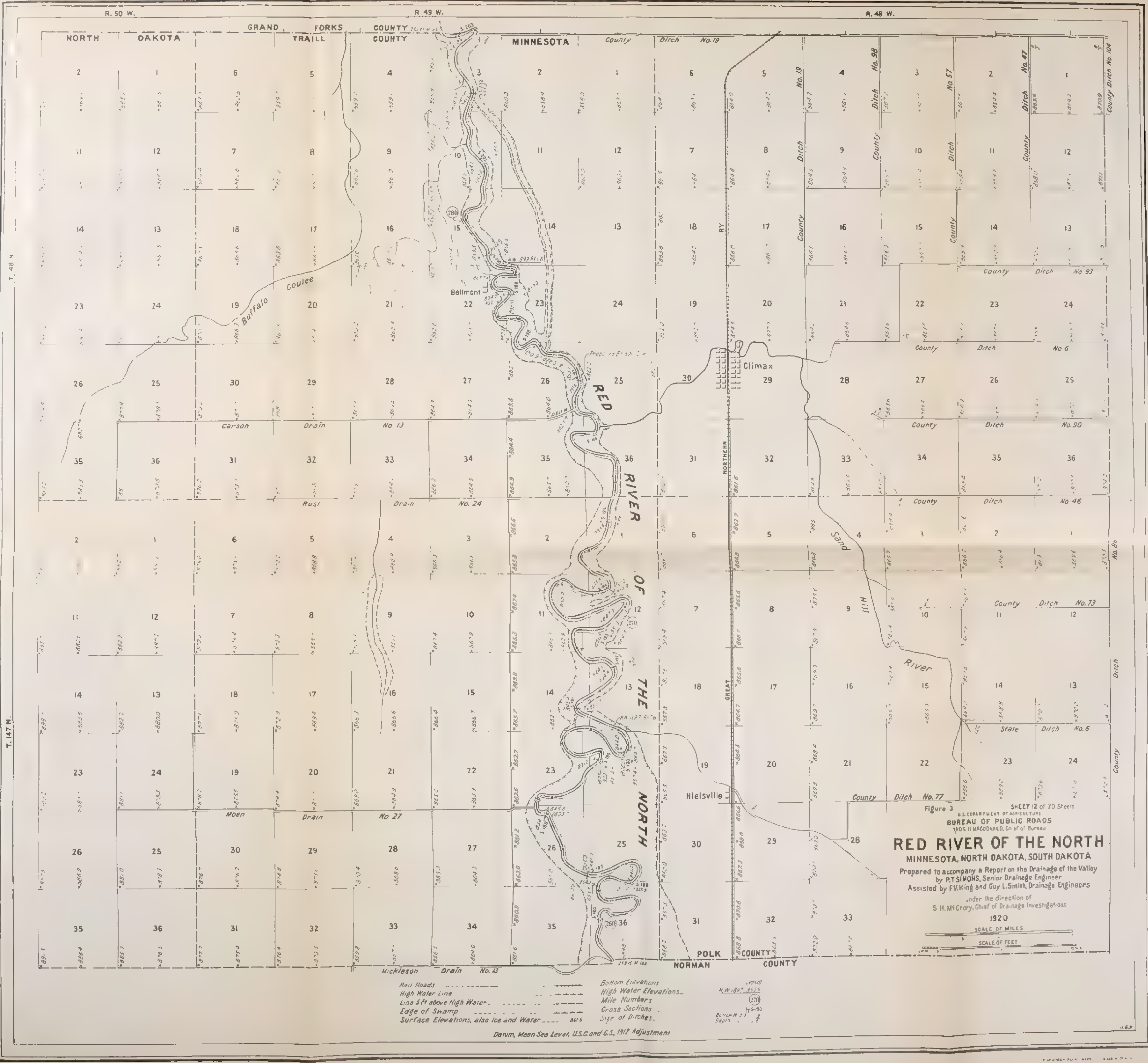

Figure 3

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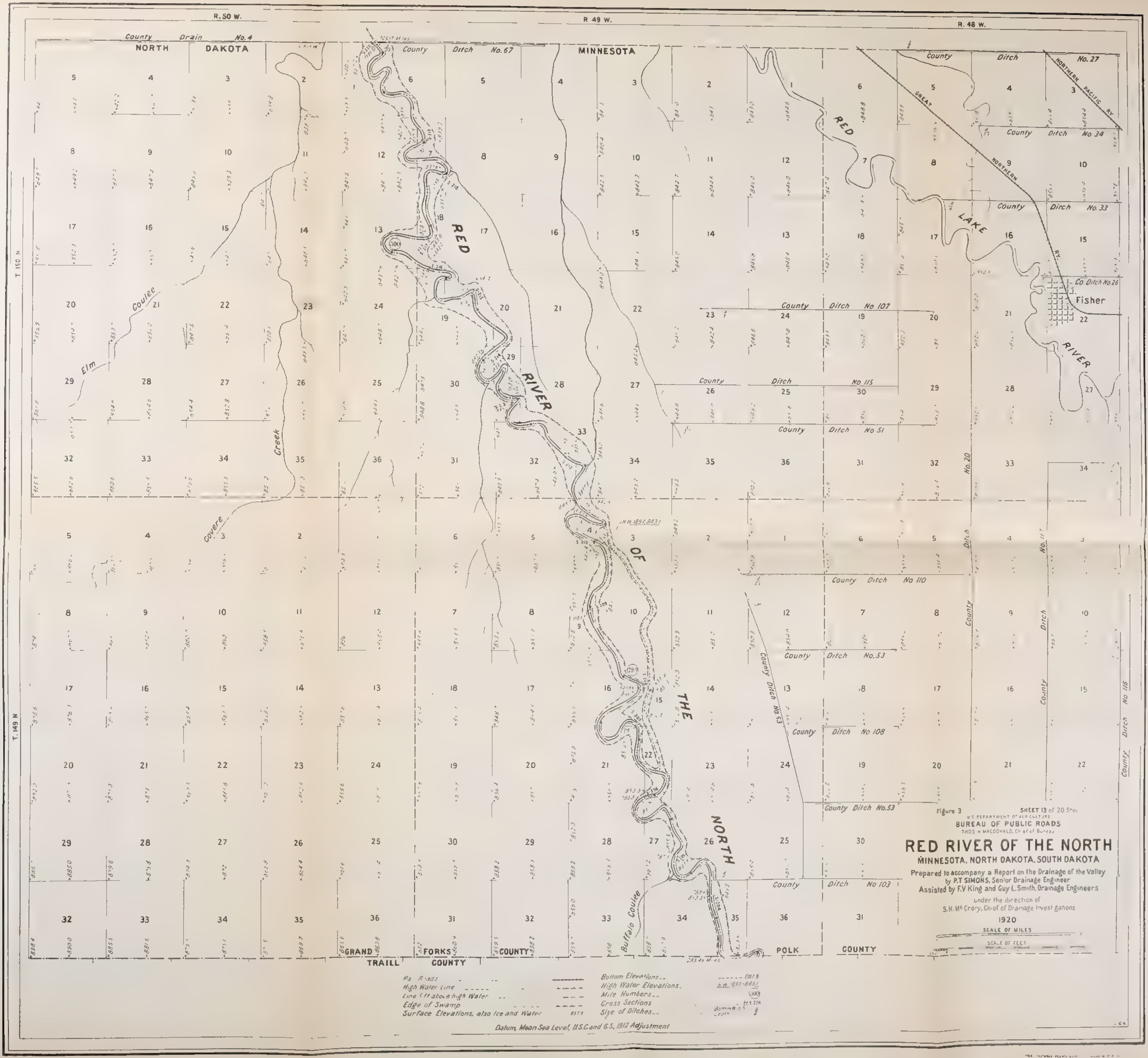

Figure 3

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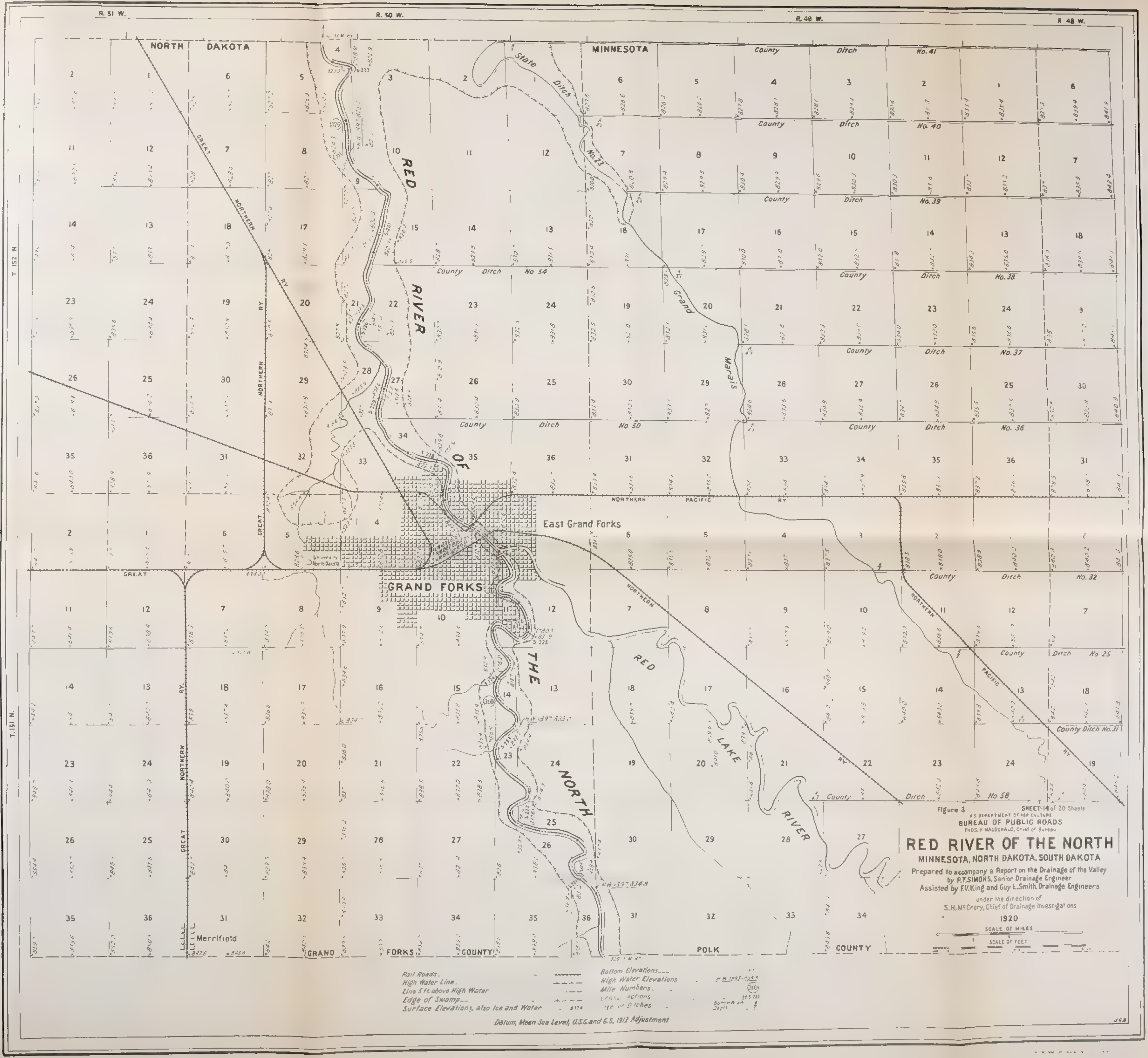

Figure 3

SHEET 14 of 20 Sheets

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SCALE OF MILES

SCALE OF FEET

| | | | |
|---|---|---|---|
| Rail Roads | ━━━━ | Bottom Elevations | |
| High Water Line | – – – – | High Water Elevations | H.W. 1897 - 834.8 |
| Line 5 ft. above High Water | – — — | Mile Numbers | (310) |
| Edge of Swamp | – – – – | Cross Sections | H S 223 |
| Surface Elevations, also Ice and Water | 8174 | Size of Ditches | Bottom Width<br>Depth |

Datum, Mean Sea Level, U.S.C. and G.S., 1912 Adjustment

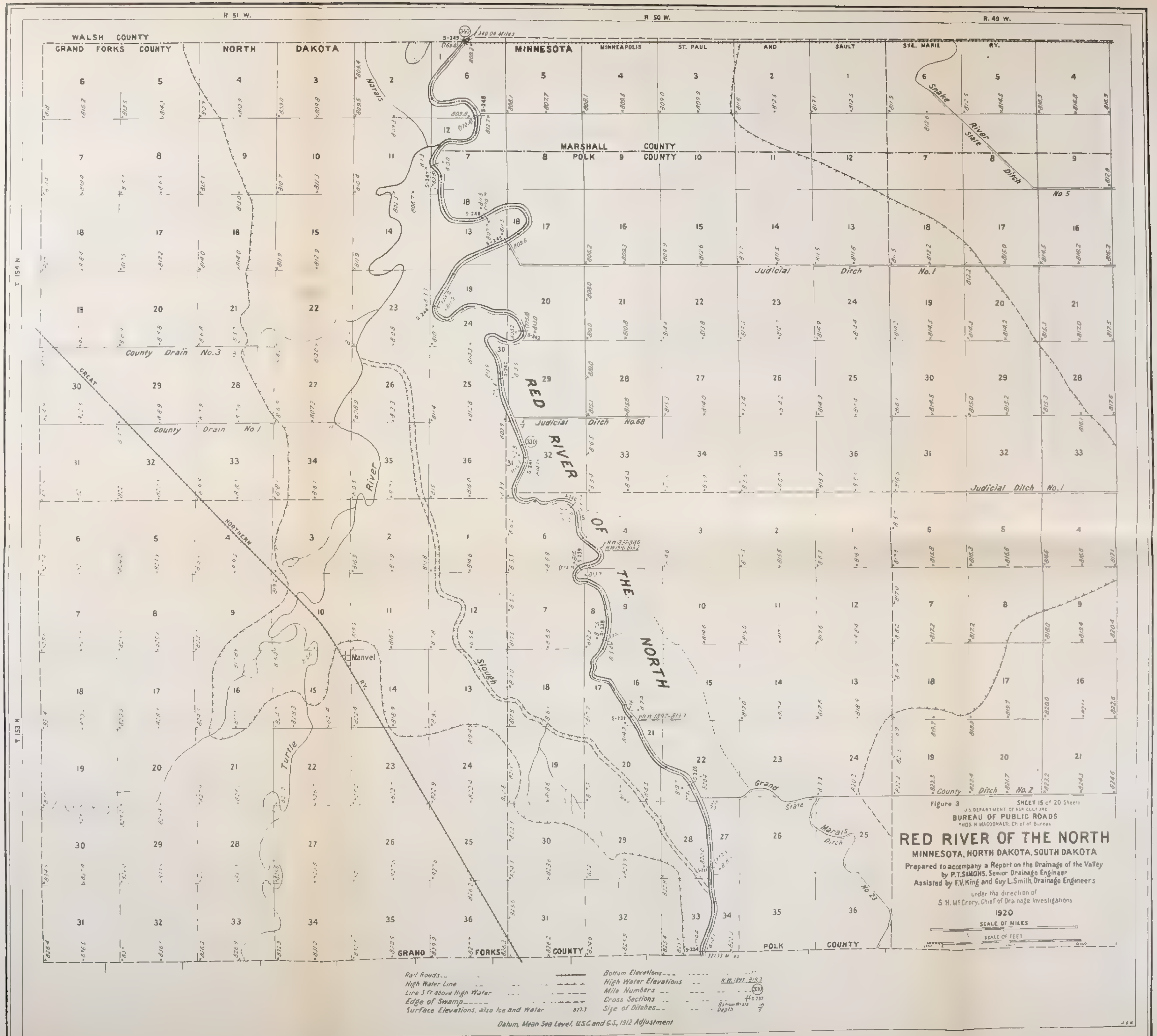

Figure 3

SHEET 15 of 20 Sheets

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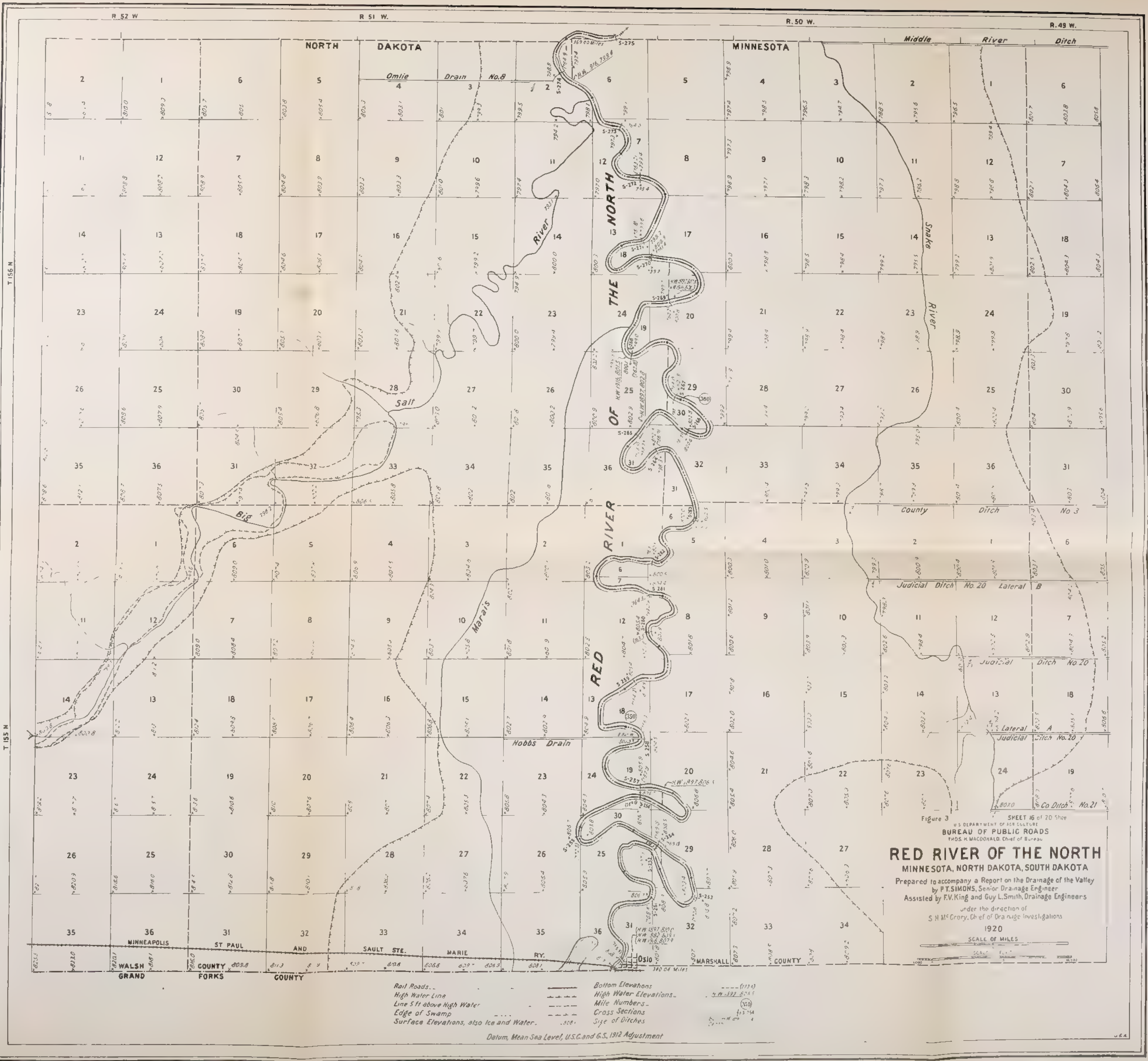

Figure 3

SHEET 16 of 20 Shee

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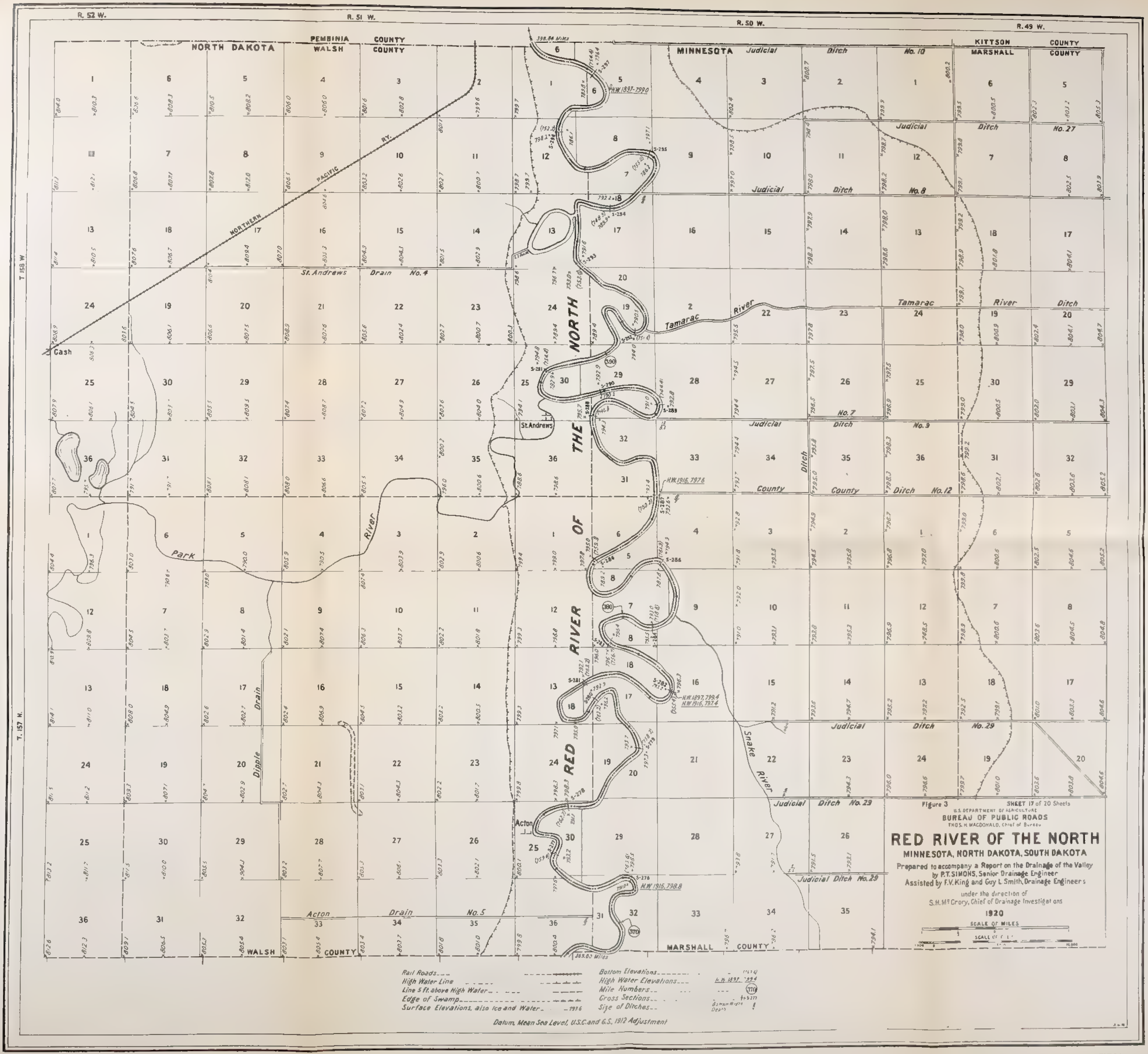

Figure 3

SHEET 17 of 20 Sheets

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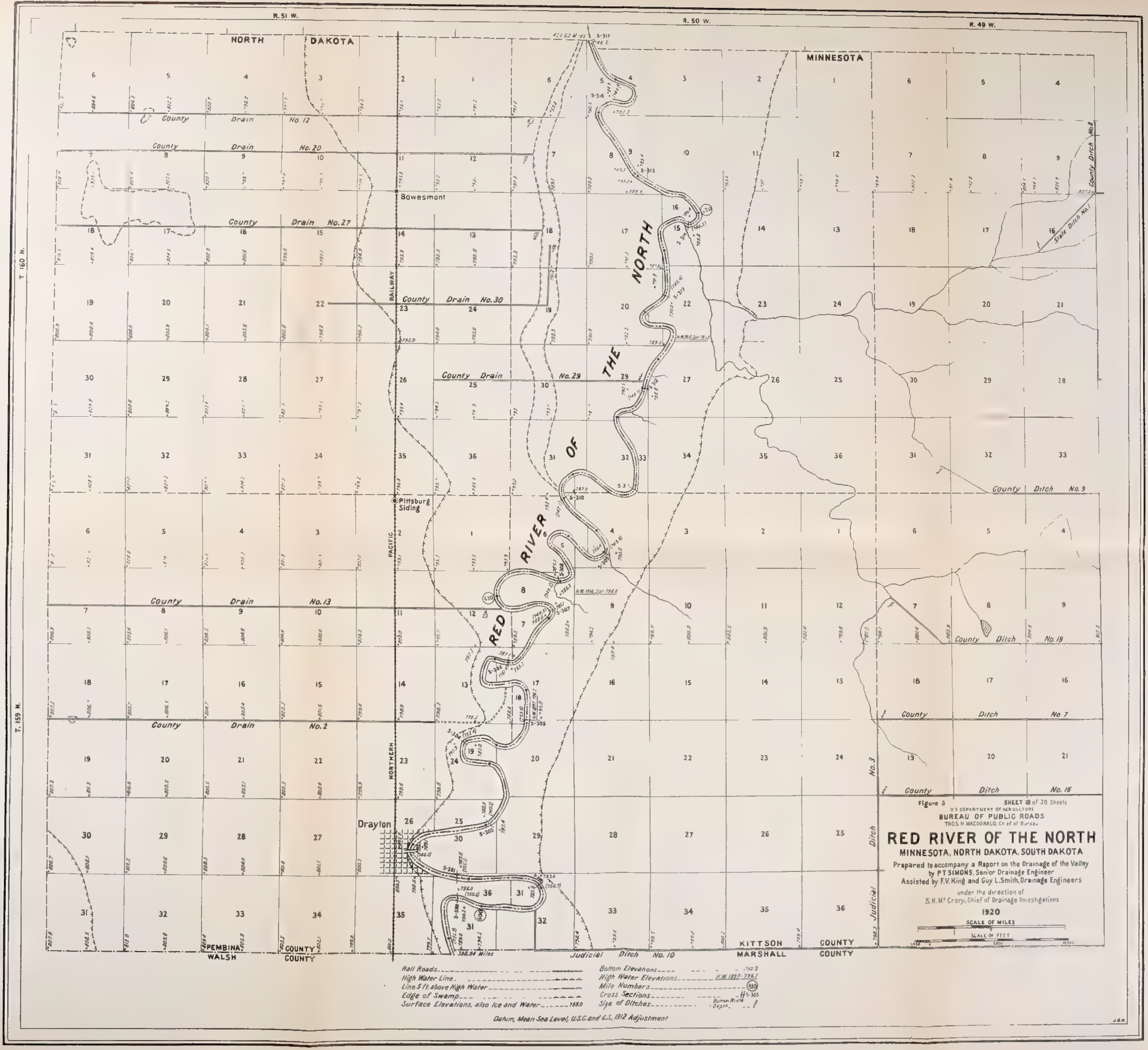

Figure 3

SHEET 18 of 20 Sheets

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SCALE OF MILES

SCALE OF FEET

1017, U S Dept of Agriculture

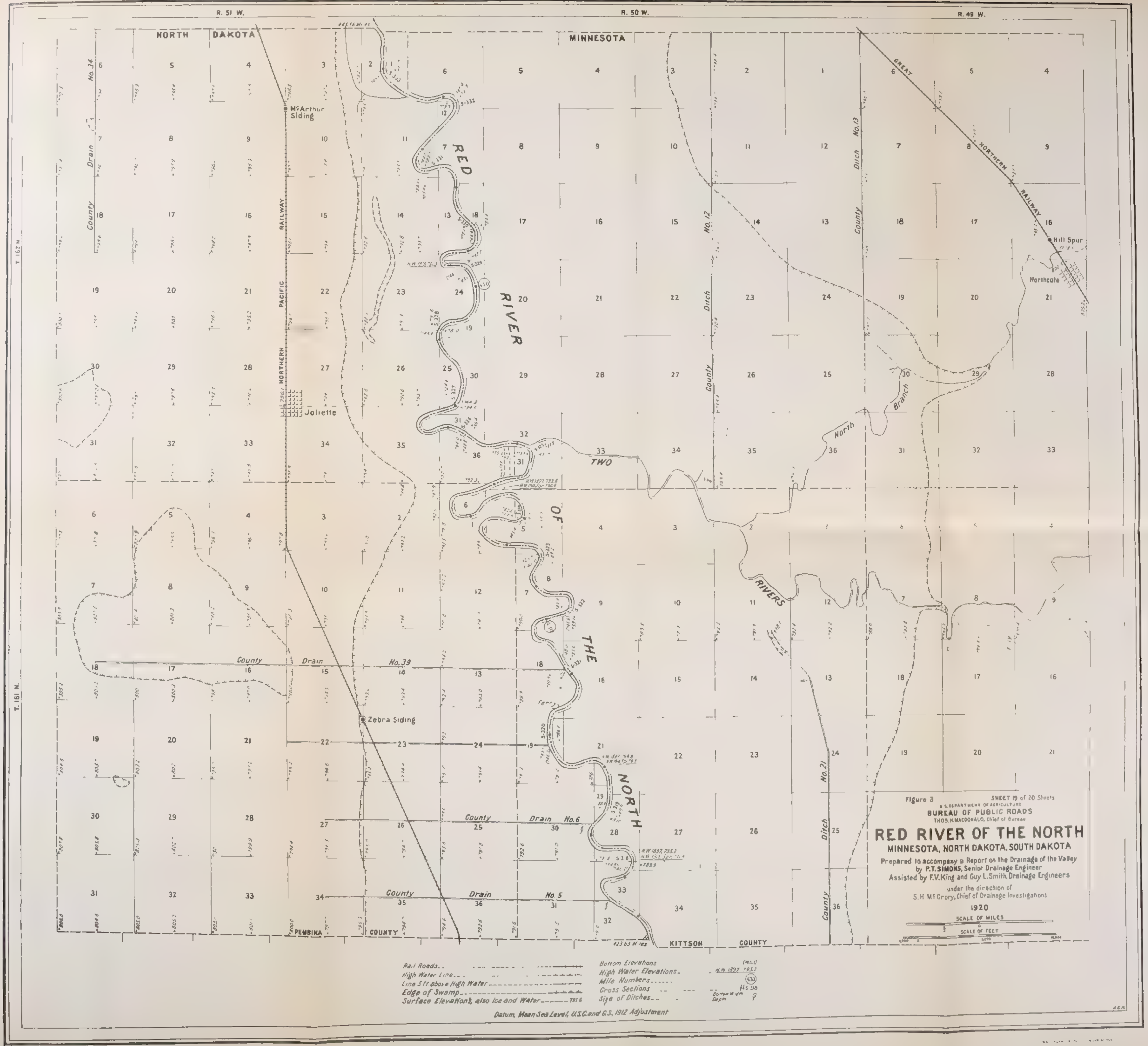

Figure 3

SHEET 19 of 20 Sheets

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THOS. H. MACDONALD, Chief of Bureau

RED RIVER OF THE NORTH
MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA

Prepared to accompany a Report on the Drainage of the Valley
by P.T. SIMONS, Senior Drainage Engineer
Assisted by F.V. King and Guy L. Smith, Drainage Engineers

under the direction of
S. H. McCrory, Chief of Drainage Investigations

1920

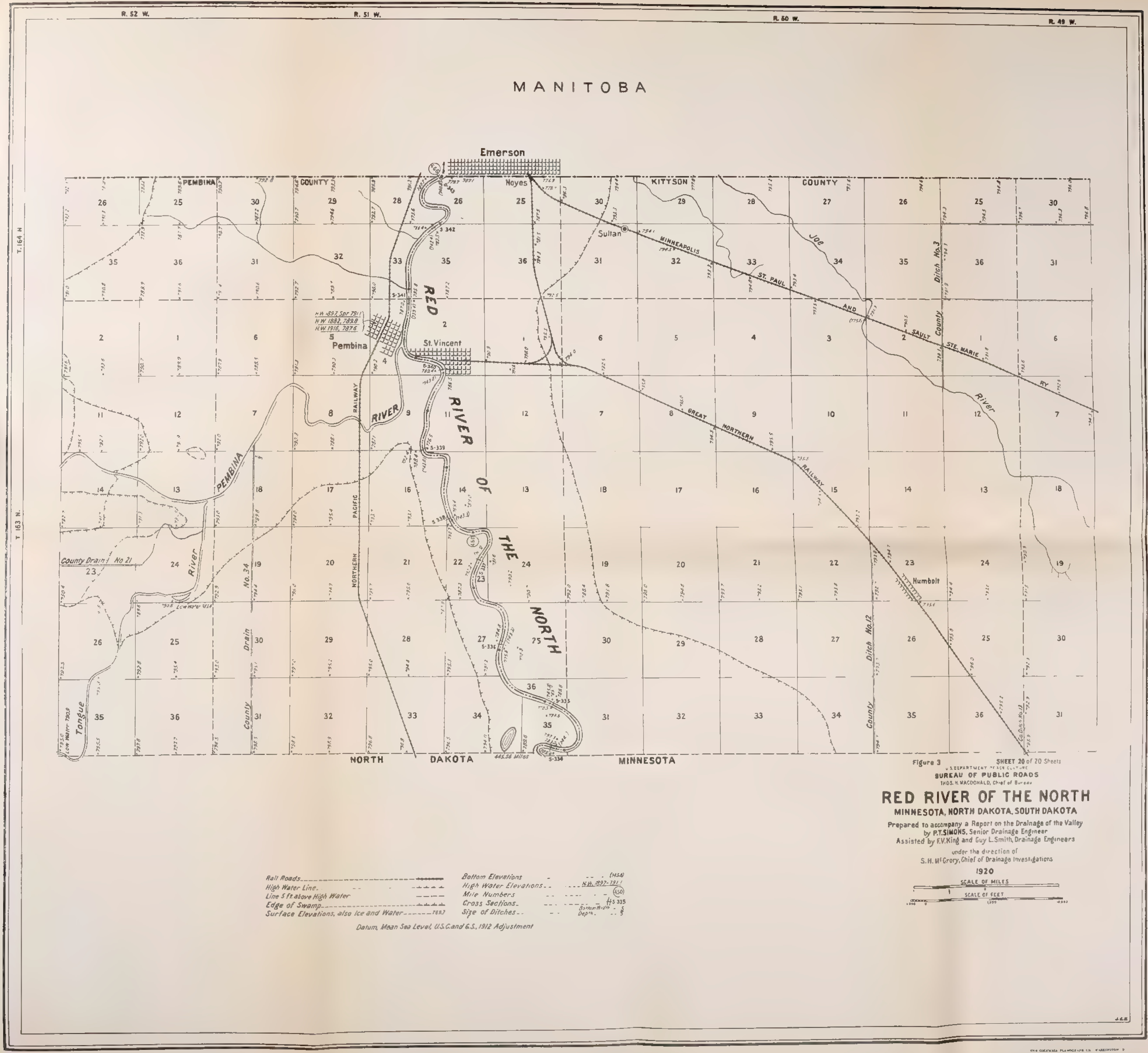

Figure 3

SHEET 20 of 20 Sheets

U. S. DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
THOS. H. MACDONALD, Chief of Bureau

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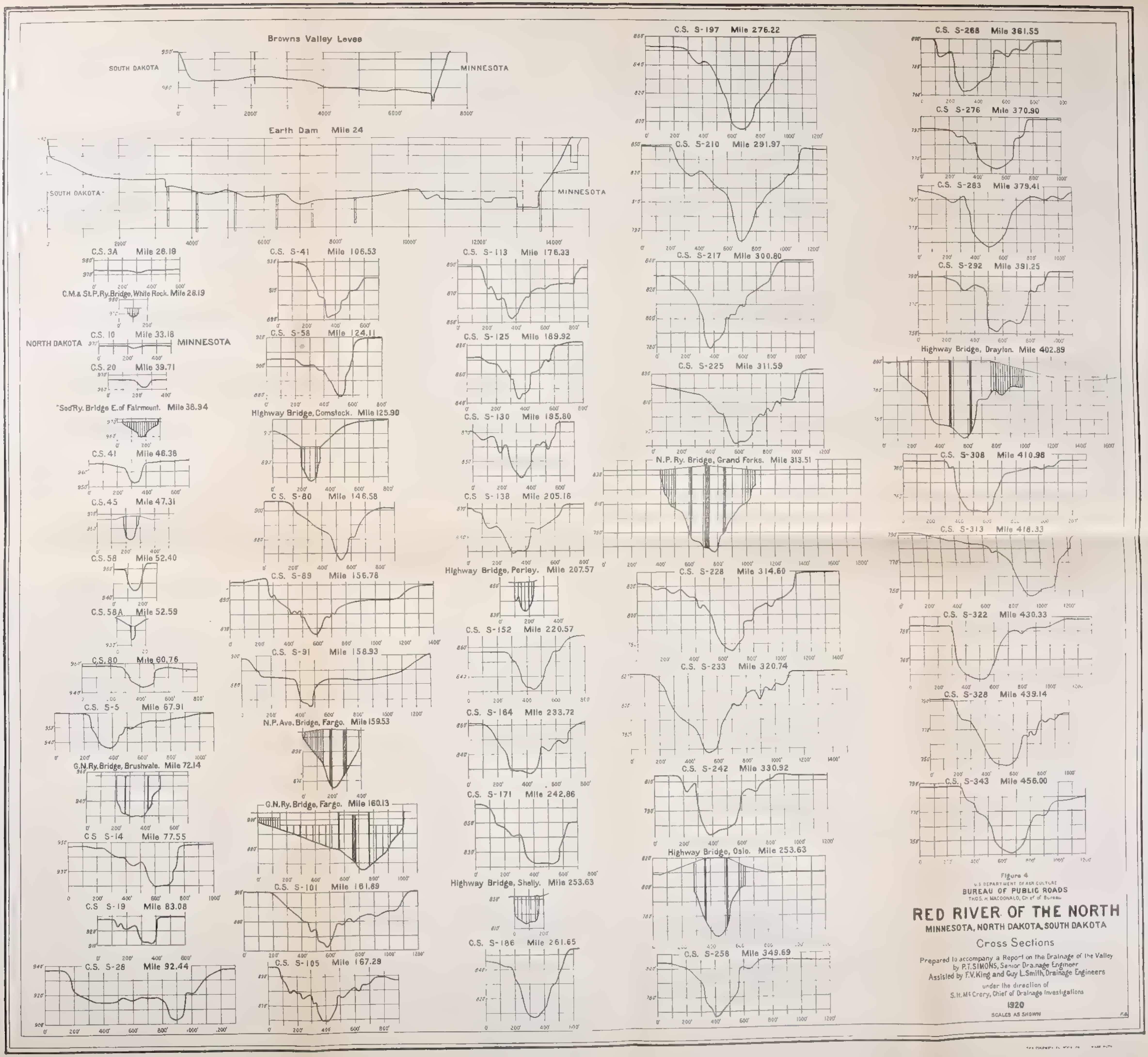

Figure 4

U. S. DEPARTMENT OF AGRICULTURE
**BUREAU OF PUBLIC ROADS**
THOS. H. MACDONALD, Chief of Bureau

# RED RIVER OF THE NORTH

## MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA

## Cross Sections

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SCALES AS SHOWN

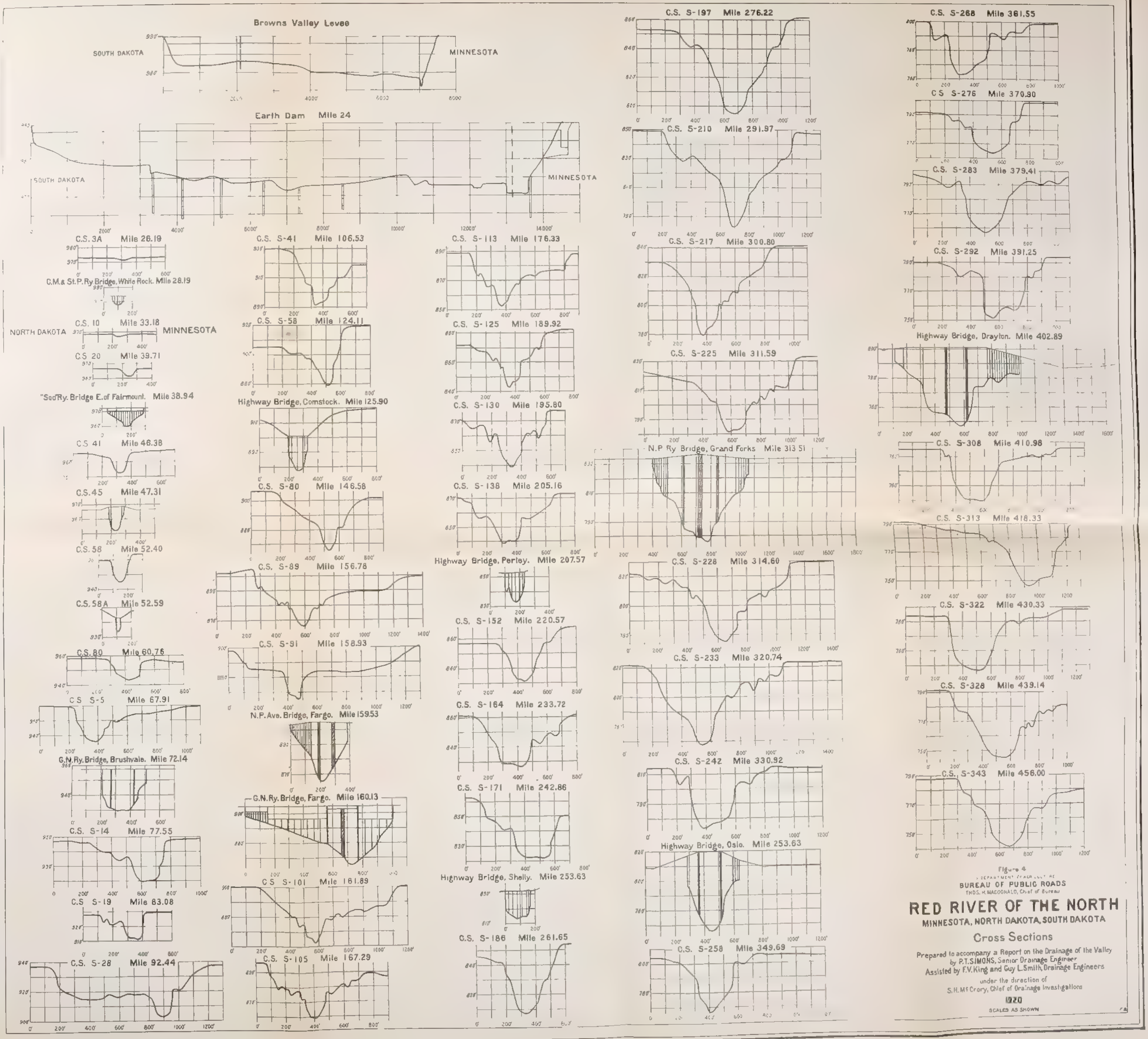

Figure 4

U. S. DEPARTMENT OF AGRICULTURE
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# RED RIVER OF THE NORTH

## MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA

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were tabulated or plotted as curves showing various relations. Run-off records were studied and the problem of the relation between precipitation and run-off was approached from various angles in an effort to reach reliable conclusions as to maximum rates of flow which may occur in the different parts of the Red River, the coincidence of heavy flow in the various tributaries, and the probable time intervals between damaging flood stages.

### DRAINAGE.

The drainage situation over the watershed was studied in considerable detail. The flat land along both sides of the main watercourse was considered separately from the higher, backlying areas, as its drainage is more intimately related to the conditions of flow in the main channel. Areas affected by present drainage of these flats were determined and estimates made as to probable future drainage and its effects.

Considerable areas of land along the Bois de Sioux River lie only slightly higher than the normal water surface in that stream. Under high-water conditions these lands are submerged and form a part of the bed of Lake Traverse. At all times these areas are marshy and unfit for agricultural purposes. Estimates were made as to the amount of such land reclaimable and the extent of improvement possible. Details for the complete drainage of the areas were not worked out, but plans for the main channel improvement of the Bois de Sioux include the layout of main outlet ditches necessary for the disposal of overflow water and of the flow from future local drains.

The general conditions of drainage systems in all parts of the watershed were investigated. The question of tile drainage, its probable development and general effect on the outlet channels, was also considered.

### FLOODS.

In studying the flood situation the main object was to determine as accurately as possible the extent of damaging flow with corresponding river stages, the probable frequency and magnitude of future floods, and the maximum flow that may be expected. The studies of precipitation, run-off, and effects of drainage were made mainly for this purpose. Information concerning floods from whatever source was considered and given such weight as its importance and reliability seemed to warrant.

### MEASURES FOR RELIEF.

Relief measures were considered under two heads, drainage and flood relief. The question of draining the wet lands along the Bois de Sioux River was taken up along with that of the detention reservoir for the control of run-off from the Lake Traverse watershed, as together they form a single interstate project for combined drainage and flood prevention for that territory. The improvement of the Red River channel is an interstate proposition and the increase of its capacity is a measure for the prevention of floods. When proper provision has been made for the removal of the water that may come to the channel from the several States, the drainage of the land along its course becomes a matter of locally controlled projects, and is so considered in this report.

The Bois de Sioux-Red River channel was studied in detail with respect to size, course, slope, and condition as to obstruction. Various methods of increasing the capacity were considered and conclusions reached as to their effectiveness and practicability. Widening and deepening of the channel; cut-offs; removal of brush, trees, and débris; relocation of bridges; and changes in points of entry of tributary streams by means of stream diversion and artificial embankment—these were all considered in some location or other, wherever applicable.

As the study of flood flow and channel capacities made it apparent that complete relief from flood conditions can not be economically secured through channel improvement alone, the possibility of reducing high-water stages by means of temporary storage in the upper reaches of the streams was investigated. The only locations which seem to offer practicable opportunities in this respect are the Red Lake and Lake Traverse regions. The former has been investigated by engineers of the War Department, which has reported favorably upon the proposed improvement.[3] An abstract of that report appears in another part of this report. The effect of that project upon Red River conditions has been considered in the present investigation.

A thorough field study was made of the Lake Traverse region to determine the most advantageous location for a reservoir and its efficiency under extreme conditions of run-off. Storage capacities for various stages were computed and tentative plans were prepared for the necessary controlling works. The results of such storage in the case of the territory immediately benefited, and its effect upon the conditions of flow in the Red River, were considered.

The plans for recommended improvements were worked up with the view of securing the maximum benefits at the least cost and an equitable distribution of these two factors among all concerned.

## RUN-OFF.

Run-off is that portion of the precipitation which, falling upon a watershed, flows over or through the earth to a watercourse and thence out of the watershed. Precipitation is the source of run-off, but many different factors affect the amount and rate of run-off from a given watershed. A portion of the water is absorbed by the soil; some of this passes through the soil into drainage channels. A part is evaporated from the soil or is transpired by plants and trees or is evaporated from the surface of the soil. A small amount sinks deep into the ground, and the remainder passes over the surface of the ground to a watercourse and through it out of the watershed. The rate and amount of run-off from a watershed are affected principally by the amount and distribution of the precipitation and its form—whether rain or snow.

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[3] Document No. 61, House of Representatives, 66th Cong., 1st sess.

After precipitation the principal factors which affect the rate of run-off from a watershed are topography, size and shape of the watershed, prevailing temperature, character of vegetation on the watershed, and artificial drainage. In addition to these and somewhat dependent upon them are evaporation, transpiration of plants, absorption by the soil, and storage, all of which tend to regulate the amount of water reaching drainage channels. The effect of these several factors upon the amount and rate of run-off is not constant but is continually changing. It is exceedingly difficult, if not impossible, to measure the effect of the various factors upon the run-off, and in the absence of measurements from a given watershed the determination of the probable rate of run-off becomes a complex problem.

The best bases for calculating future run-off are measurements of stream flow extending over a long period of time for the particular watershed under consideration. If such records are available, the amount and rate of run-off can be estimated closely unless the physical features which affect run-off from the watershed are materially changed. If complete data for a long period are not available, then records for a shorter time on the watershed under consideration, or on more or less similar watersheds, are most essential. For the watershed of the Red River, and especially for those of its tributaries, the run-off records are meager because settlement and development in the valley are only comparatively recent.

Daily records of the river stage at Grand Forks, from which the run-off at that point can be computed, are available as far back as 1882. From 1882 to 1901 the gauge readings were recorded by the Corps of Engineers, United States Army, and from 1902 to the present time by the United States Geological Survey. Similar records are available for the Red River at Fargo from 1902 to the present time, as are also records for 12 stations on tributary streams for periods of from 1 to 17 years, since 1901. The daily flow of the river at Emerson, Manitoba, just north of the international boundary, has been recorded since May, 1912, by the Manitoba Hydrometric Survey. A list of these available records of stream discharge is given in Table 3.

TABLE 3.—*Maximum stream discharges on Red River watershed.*

| Stream. | Station. | Watershed area, square miles. | Period. | Maximum discharge. | | Authority. |
|---|---|---|---|---|---|---|
| | | | | Rate. | Date. | |
| | | | | *Sec.-ft.* | | |
| Mustinka River | Wheaton | 756 | 1917–1919 | 2,240 | Apr. 1, 1917 | U. S. Geological Survey and U. S. Department of Agriculture. |
| Bois de Sioux River | Fairmount | 1,480 | 1919–1920 | 255 | Mar. 24, 1920 | U. S. Department of Agriculture. |
| Otter Tail River | Fergus Falls | 1,300 | 1900–1917 | 1,080 | June 13, 1904 | U. S. Engineers and U. S. Geological Survey. |
| North Dakota Wild Rice River. | Mouth, Wild Rice. | 2,210 | 1919–1920 | 1,779 | Mar. 24, 1920 | U. S. Department of Agriculture. |
| Red River | Fargo-Moorhead | 6,435 | 1902–1919 | 7,720 | July 11, 1916 | Do. |
| Sheyenne River | Valley City | 4,185 | 1919 | 2,750 | Apr. 18, 1919 | Do. |
| Do | Haggart | 5,600 | 1902–1907, 1919 | 2,220 | Apr. 28, 1919 | U. S. Geological Survey and U. S. Department of Agriculture. |
| Minnesota Wild Rice River. | Twin Valley | 835 | 1909–1917 | 9,120 | July 22, 1909 | U. S. Geological Survey. |
| Thief River | Thief River Falls | 1,080 | 1909–1917 | 4,100 | Apr. 23, 1916 | Do. |
| Red Lake River and Thief River. | do | 3,600 | ........ | 7,600 | July 3, 1919 | |
| Clearwater River | Red Lake Falls | 1,330 | 1909–1919 | 6,700 | do | Do. |
| Red Lake River | Crookston | 5,320 | 1901–1919 | 14,400 | Apr. 17, 1916 | Do. |
| Red River | Grand Forks | 25,755 | 1882–1919 | 43,000 | Apr. 10, 1897 | U. S. Engineers and U. S. Geological Survey. |
| Two Rivers | Hallock | 635 | 1911–1914 | 1,200 | Apr. 13, 1913 | U. S. Geological Survey. |
| Pembina River | Neche | 3,320 | 1903–1915, 1919 | 3,870 | May 2, 1904 | Do. |
| Red River | Emerson, Manitoba | 35,895 | 1912–1919 | 46,180 | Apr. 24, 1916 | Manitoba Hydrometric Survey. |

As indicated in the table, the Geological Survey has made most of the stream-flow measurements. This work was done in connection with the determination of the water supply of the United States.[4]

A limited number of measurements of stream flow were made by the Department of Agriculture in connection with the survey of Red River during 1919 and 1920. Of these the principal measurements were: The Sheyenne River at Valley City and at Haggart, N. Dak., during March and April, 1919; the Wild Rice River at Wild Rice, N. Dak., March, 1920; and the Bois de Sioux River at Fairmount, N. Dak., March, 1920. These records are valuable because quite high stages occurred during the periods mentioned and because no previous gagings had been made at three of the stations.

The records of stream flow at Grand Forks are shown in Table 4. The quantities of run-off were computed from daily gage readings except for January, February, March, and December, 1882, to 1900, for which periods no gage records are available. For those months estimates were made from records for corresponding months from 1901 to 1919. The estimates of annual run-off are only slightly affected by the December-March figures, so the annual quantities for the entire period of 38 years are considered to be reasonably accurate.

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[4] U. S. Geol. Survey, Water Supply Papers 405, 435, 455, etc.

TABLE 4.—*Run-off (in billions of cubic feet) from the Red River watershed above Grand Forks, N. Dak.*

| Year. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Yearly totals. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1882 | 2.46 | 1.96 | 4.28 | 62.48 | 47.43 | 20.89 | 17.03 | 10.91 | 6.95 | 6.94 | 5.24 | 3.06 | 189.63 |
| 1883 | 2.46 | 1.96 | 4.28 | 34.00 | 46.12 | 15.13 | 8.75 | 5.78 | 4.16 | 4.09 | 4.25 | 3.06 | 134.04 |
| 1884 | 2.46 | 1.96 | 4.28 | 27.28 | 14.42 | 11.66 | 7.36 | 4.63 | 7.36 | 10.40 | 8.44 | 3.06 | 103.31 |
| 1885 | 2.46 | 1.96 | 4.28 | 17.46 | 13.81 | 13.89 | 17.52 | 14.92 | 7.87 | 5.98 | 5.29 | 3.06 | 108.50 |
| 1886 | 2.46 | 1.96 | 4.28 | 18.48 | 17.64 | 8.08 | 5.01 | 2.39 | 1.61 | 1.90 | 2.60 | 3.06 | 69.47 |
| 1887 | 2.46 | 1.96 | 4.28 | 9.81 | 5.74 | 4.02 | 3.69 | 3.73 | 2.81 | 2.12 | 1.82 | 3.06 | 45.50 |
| 1888 | 2.46 | 1.96 | 4.28 | 26.35 | 13.63 | 23.38 | 14.20 | 6.82 | 3.12 | 2.88 | 2.98 | 3.06 | 105.12 |
| 1889 | 2.46 | 1.96 | 4.28 | 6.63 | 4.04 | 2.27 | 1.90 | 1.53 | 1.39 | 1.69 | 1.53 | 3.06 | 32.74 |
| 1890 | 2.46 | 1.96 | 4.28 | 6.17 | 3.26 | 4.05 | 3.57 | 1.67 | 2.13 | 2.61 | 2.61 | 3.06 | 37.83 |
| 1891 | 2.46 | 1.96 | 4.28 | 11.25 | 4.98 | 3.90 | 4.37 | 3.85 | 2.46 | 4.07 | 4.07 | 3.06 | 50.71 |
| 1892 | 2.46 | 1.96 | 4.28 | 47.78 | 24.60 | 20.13 | 10.65 | 4.45 | 3.70 | 3.30 | 2.37 | 3.06 | 128.74 |
| 1893 | 2.46 | 1.96 | 4.28 | 43.53 | *42.72* | 9.84 | 6.64 | 3.62 | 2.55 | 2.73 | 2.30 | 3.06 | 125.69 |
| 1894 | 2.46 | 1.96 | 4.28 | 28.70 | 17.18 | 9.10 | 4.90 | 2.43 | 1.57 | 2.34 | 2.00 | 3.06 | 79.98 |
| 1895 | 2.46 | 1.96 | 4.28 | 4.80 | 2.99 | 4.55 | 4.63 | 2.45 | 1.67 | 1.73 | 2.00 | 3.06 | 36.58 |
| 1896 | 2.46 | 1.96 | 4.28 | 20.59 | 35.18 | *32.48* | 8.39 | 4.57 | 3.48 | 3.35 | 3.10 | 3.06 | 122.90 |
| 1897 | 2.46 | 1.96 | 4.28 | *81.92* | 24.75 | 9.82 | 26.13 | *19.20* | 7.77 | 5.85 | 3.68 | 3.06 | *190.88* |
| 1898 | 2.46 | 1.96 | 4.28 | 8.48 | 6.19 | 8.57 | 10.62 | 4.87 | 3.77 | 4.32 | 4.14 | 3.06 | 62.72 |
| 1899 | 2.46 | 1.96 | 4.28 | 14.07 | 11.06 | 14.19 | 11.88 | 6.49 | 4.67 | 4.41 | 3.93 | 3.06 | 82.46 |
| 1900 | 2.46 | 1.96 | 4.28 | 7.32 | 3.44 | 1.92 | 2.13 | 2.86 | 7.54 | *16.58* | *13.64* | 3.06 | 67.19 |
| 1901 | 2.92 | 2.41 | 5.12 | 28.76 | 17.99 | 12.44 | 10.67 | 6.37 | 4.70 | 5.02 | 4.49 | 3.65 | 104.54 |
| 1902 | 2.46 | 1.96 | 4.28 | 16.50 | 21.62 | 16.97 | 8.89 | 5.32 | 7.73 | 8.37 | 6.85 | 3.06 | 104.01 |
| 1903 | 4.28 | 3.43 | 5.64 | 27.58 | 14.49 | 8.66 | 3.86 | 2.82 | 4.91 | 7.99 | 5.71 | 5.26 | 94.63 |
| 1904 | 3.70 | 3.10 | 4.00 | 50.50 | 36.79 | 15.62 | 10.48 | 4.72 | 4.18 | 4.98 | 4.12 | 3.24 | 145.43 |
| 1905 | 2.70 | 2.30 | 4.60 | 7.50 | 21.80 | 12.51 | 11.29 | 17.59 | *11.70* | 8.96 | 6.61 | 5.30 | 112.86 |
| 1906 | *4.70* | *3.84* | 5.05 | 51.50 | 22.10 | 15.72 | 12.22 | 8.55 | 6.42 | 5.89 | 5.58 | 4.36 | 145.93 |
| 1907 | 3.76 | 2.64 | 8.24 | 38.39 | 12.20 | 15.58 | 8.80 | 5.36 | 5.06 | 5.27 | 3.74 | 3.22 | 112.26 |
| 1908 | 2.38 | 2.00 | 5.27 | 25.55 | 15.52 | 18.50 | 8.80 | 5.27 | 4.58 | 3.86 | 3.24 | 2.21 | 97.18 |
| 1909 | 1.87 | 1.36 | 2.48 | 11.25 | 8.28 | 8.06 | 10.12 | 15.00 | 8.32 | 5.97 | 4.93 | *6.49* | 84.13 |
| 1910 | 4.08 | 3.15 | *22.60* | 20.40 | 11.65 | 5.06 | 2.31 | 1.31 | 1.11 | 1.11 | 1.03 | .83 | 74.64 |
| 1911 | .56 | .45 | 2.40 | 4.88 | 4.01 | 4.57 | 1.55 | 1.05 | 1.01 | 1.24 | .96 | .91 | 23.59 |
| 1912 | .37 | .28 | .80 | 6.42 | 4.49 | 2.92 | 1.87 | 1.50 | 1.96 | 3.48 | 2.11 | 1.13 | 27.33 |
| 1913 | .85 | .56 | .76 | 18.28 | 4.88 | 3.08 | 2.76 | 2.04 | 2.76 | 2.81 | 2.95 | 2.12 | 43.85 |
| 1914 | 1.36 | 1.04 | 2.44 | 7.75 | 6.86 | 12.48 | 7.61 | 2.92 | 3.06 | 3.39 | 3.50 | 3.12 | 55.53 |
| 1915 | 2.09 | 1.79 | 3.12 | 10.77 | 8.64 | 14.90 | 29.58 | 6.45 | 4.02 | 4.32 | 3.84 | 3.32 | 92.84 |
| 1916 | 2.26 | 1.68 | 2.86 | 57.60 | 29.46 | 17.58 | *30.40* | 13.20 | 10.28 | 8.20 | 7.20 | 4.75 | 185.47 |
| 1917 | 3.27 | 2.25 | 4.71 | 30.19 | 12.81 | 5.66 | 3.16 | 1.60 | 1.45 | 1.58 | 2.06 | 1.16 | 69.90 |
| 1918 | .71 | .48 | 4.00 | 4.69 | 4.96 | 5.08 | 2.26 | 1.94 | 1.47 | 1.09 | 1.69 | 1.80 | 30.17 |
| 1919 | 1.20 | .60 | 2.99 | 14.36 | 8.98 | 4.79 | 18.55 | 8.98 | 3.59 | 3.14 | 3.69 | 4.10 | 74.97 |
| Mean annual | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 90.87 |

NOTE.—Mean rate of flow 1882 to 1919=2,881 sec.-ft. Maximums shown in italics.

Run-off data for all of the watersheds listed in Table 3 were compiled in the same form as shown in Table 4 for Grand Forks, but the tables are not here given as all the records are now available, or soon will be, either in Water Supply Papers of the United States Geological Survey or in reports of the Dominion Water Power Branch, Department of the Interior, Canada.

The Grand Forks records cover the longest period of any in the Red River watershed and form, therefore, a basis for estimating probable future run-off quantities and rates of flow with a degree of accuracy that may not be attained where the records cover short periods only.

When all available records had been compiled it was found that of the various watersheds listed in Table 5, run-off estimates for 16 (those listed in Table 3) may be based in part on measured run-off and in part on data resulting from a consideration of the various factors that affect run-off. That method must suffice also for eight other watersheds for which run-off has been measured on only parts of the areas. For the remaining 23 watersheds, estimates must be based entirely on a consideration of the various factors that affect run-off and comparisons with measured run-off from watersheds having somewhat similar characteristics.

TABLE 5.—*Recorded and estimated future maximum discharges from streams on Red River watershed.*

| Stream. | Station. | Watershed area. | Period of measurements. | During summer floods. | | | During spring floods. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Maximum recorded discharge. | Estimated future maximum— | | Maximum recorded discharge. | Estimated future maximum— | |
| | | | | | Discharge. | Run-off. | | Discharge. | Run-off. |
| | | *Sq. mi.* | *Years.* | *Sec.-ft.* | *Sec.-ft.* | *Sec.-ft. per sq. mi.* | *Sec.-ft.* | *Sec.-ft.* | *Sec.-ft. per sq. mi.* |
| Small streams | Browns Valley to Mustinka River. | 291 | ........ | ........ | 1,455 | 5 | ........ | 1,455 | 5 |
| Mustinka River. | Wheaton | 756 | 2 | ........ | 3,024 | 4 | 2,240 | 3,024 | 4 |
| Do | Mouth | 852 | ........ | ........ | 3,408 | 4 | ........ | 3,408 | 4 |
| Small streams | Mustinka River to White Rock. | 192 | ........ | ........ | 960 | 5 | ........ | 960 | 5 |
| Lake Traverse outlet. | White Rock | 1,335 | ........ | ........ | 2,670 | 2 | ........ | 2,670 | 2 |
| Small streams | Fairmount | 145 | ........ | ........ | 725 | 5 | ........ | 725 | 5 |
| Bois de Sioux River. | do | 1,480 | 1 | ........ | 2,960 | 2 | 255 | 2,960 | 2 |
| Small streams | Fairmount to Breckenridge. | 395 | ........ | ........ | 1,975 | 5 | ........ | 1,975 | 5 |
| Bois de Sioux River. | Wahpeton | 1,875 | ........ | ........ | 3,750 | 2 | ........ | 3,750 | 2 |
| Otter Tail River. | Fergus Falls | 1,300 | 18 | 1,080 | 1,560 | 1.2 | 789 | 1,820 | 1.4 |
| Otter Tail River tributaries. | Below Fergus Falls | 540 | ........ | ........ | 2,160 | 4 | ........ | 2,160 | 4 |
| Otter Tail River. | Breckenridge | 1,840 | ........ | ........ | 3,312 | 1.8 | ........ | 3,680 | 2 |
| Small streams | Breckenridge to North Dakota Wild Rice River. | 445 | ........ | ........ | 1,780 | 4 | ........ | 1,780 | 4 |
| Red River | Above mouth of North Dakota Wild Rice River. | 4,160 | ........ | ........ | 6,656 | 1.6 | ........ | 8,320 | 2 |
| North Dakota Wild Rice River. | Lake Tewaukon | 625 | ........ | ........ | 1,875 | 3 | ........ | 2,500 | 4 |
| Do | Mouth, Wild Rice | 2,210 | 1 | ........ | 3,315 | 1.5 | 1,779 | 4,420 | 2 |
| Local drains | Fargo-Moorhead | 65 | ........ | ........ | 520 | 8 | ........ | 455 | 7 |
| Red River | do | 6,435 | 18 | 7,720 | 9,652 | 1.5 | 7,440 | 11,580 | 1.8 |
| Local drains | Moorhead to Sheyenne River. | 95 | ........ | ........ | 665 | 7 | ........ | 570 | 6 |
| Sheyenne River. | Valley City | 4,185 | 1 | ........ | 2,511 | 0.6 | 2,750 | 4,185 | 1 |
| Do | Haggart | 5,600 | 7 | 841 | 2,800 | 0.5 | 2,220 | 5,600 | 1 |
| Do | Mouth | 7,400 | ........ | ........ | 3,700 | 0.5 | ........ | 7,400 | 1 |
| Red River | Below Sheyenne River mouth. | 13,930 | ........ | ........ | 13,930 | 1 | ........ | 16,716 | 1.2 |
| Buffalo River | Georgetown | 1,175 | ........ | ........ | 5,875 | 5 | ........ | 5,875 | 5 |
| Minnesota Wild Rice River. | Twin Valley | 835 | 9 | 9,120 | 5,845 | 7 | 1,560 | 5,010 | 6 |
| Do | Mouth | 1,485 | ........ | ........ | 5,940 | 4 | ........ | 5,940 | 4 |

Table 5.—*Recorded and estimated future maximum discharges from streams on Red River watershed*—Continued.

| Stream. | Station. | Water-shed area. | Period of measurement. | During summer floods. | | | During spring floods. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Maximum recorded discharge. | Estimated future maximum— | | Muximum recorded discharge. | Estimated future maximum— | |
| | | | | | Discharge. | Run-off. | | Discharge. | Run-off. |
| | | *Sq. mi.* | *Years.* | *Sec.-ft.* | *Sec.-ft.* | *Sec.-ft. per sq. mi.* | *Sec.-ft.* | *Sec.-ft.* | *Sec.-ft. per sq. mi.* |
| Goose River | Mouth | 1,270 | | | 3,810 | 3 | | 3,810 | 3 |
| Sandhill River | do | 425 | | | 1,700 | 4 | | 2,550 | 6 |
| Small streams | Sheyenne River to Grand Forks. | 1,685 | | | 6,740 | 4 | | 6,740 | 4 |
| Red Lake | Outlet | 1,950 | | | 1,950 | 1 | | 2,925 | 1.5 |
| Thief River | Thief River Falls | 1,080 | 9 | 4,100 | 5,400 | 5 | 4,080 | 4,320 | 4 |
| Red Lake River and Thief River. | do | 3,600 | 10 | 7,600 | 10,800 | 3 | 7,040 | 9,000 | 2.5 |
| Clearwater River | Red Lake Falls | 1,330 | 9 | 6,700 | 6,650 | 5 | 3,990 | 6,650 | 5 |
| Red Lake River | Crookston | 5,320 | 19 | 14,400 | 15,960 | 3 | 14,400 | 15,960 | 3 |
| Do | East Grand Forks | 5,785 | | | 17,355 | 3 | | 17,355 | 3 |
| Red River | Grand Forks, N. Dak. | 25,755 | 38 | 22,360 | 36,057 | 1.4 | 43,000 | 51,510 | 2 |
| Turtle River | Mouth | 705 | | | 2,115 | 3 | | 2,115 | 3 |
| Forest River | do | 1,030 | | | 2,060 | 2 | | 3,090 | 3 |
| Snake River | do | 760 | | | 2,280 | 3 | | 2,660 | 3.5 |
| Park River | do | 885 | | | 2,212 | 2.5 | | 2,655 | 3 |
| Tamarac River | do | 365 | | | 1,460 | 4 | | 1,460 | 4 |
| Small streams | Grand Forks to Drayton. | 765 | | | 3,060 | 4 | | 3,060 | 4 |
| Two Rivers | Hallock | 635 | 4 | 634 | 2,540 | 4 | 1,200 | 2,540 | 4 |
| Do | Mouth | 975 | | | 2,925 | 3 | | 3,900 | 4 |
| Small streams | Drayton to Emerson, Manitoba. | 790 | | | 2,370 | 3 | | 3,160 | 4 |
| Pembina River | Neche | 3,320 | 12 | 2,500 | 3,984 | 1.2 | 3,870 | 4,980 | 1.5 |
| Do | Pembina | 3,865 | | | 4,638 | 1.2 | | 5,797 | 1.5 |
| Red River | International boundary. | 35,895 | 8 | 20,121 | 39,485 | 1.1 | 46,180 | 61,022 | 1.7 |

## PRECIPITATION.

As it was found that precipitation records covered longer periods of time and were available for many more localities than were stream-flow records, a study of precipitation was undertaken for the purpose of supplementing the data on run-off.

The official records of the United States Weather Bureau were used as the basis for the precipitation studies. The investigation developed that total annual, total and maximum monthly, and maximum and excessive daily and storm precipitation, are of much greater significance in the project than are mean or average quantities and rates. It developed also that accumulations of precipitation in the forms of snow and ice are important factors in estimating stream discharge for March and April.

Records of monthly and annual precipitation at Breckenridge, Minn., and Pembina, N. Dak., are available for 48 years (1872 to 1919) and at Moorhead, Minn., for 39 years (1881 to 1919). Other weather-observation stations have been established from time to time until in 1921 about 50 were maintained within the Red River watershed (see fig. 1). Daily precipitation records are available for twenty or more stations for the period 1892 to 1919.

### DISTRIBUTION OF PRECIPITATION.

In making the study of precipitation data the contributing area south of the international boundary was divided into seven areas as indicated in figure 5. This facilitated the determination of the precipitation on watersheds of various tributary streams and on areas above certain stream-gaging stations; it also made evident the relations between size of watershed and intensity of precipitation.

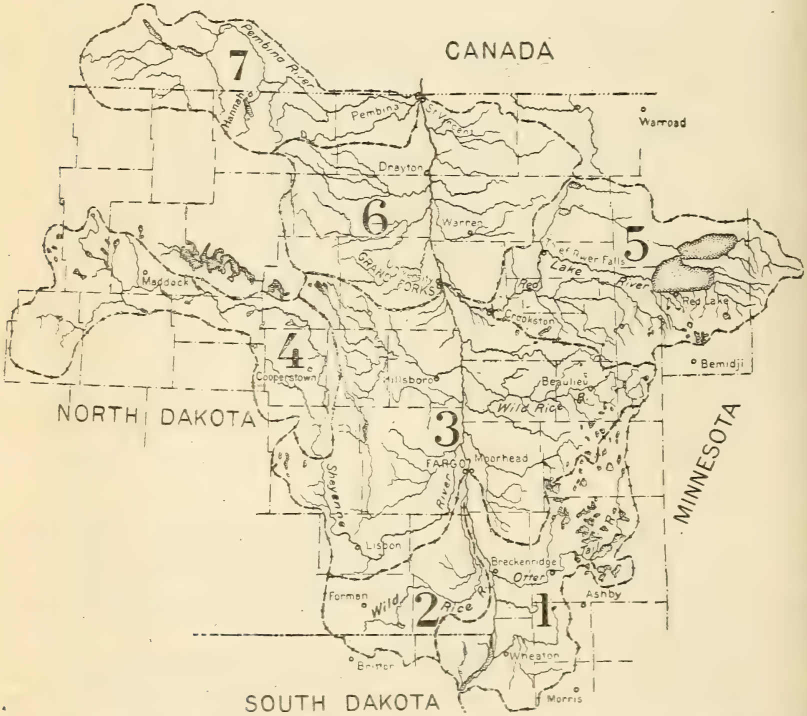

FIG. 5.—Outline watershed map of Red River of the North, showing subdivisions for precipitation studies.

The precipitation records were considered in four classes—annual, monthly, and storm periods, and the period during which snow is stored. The annual, monthly, and storm precipitations were computed from the records for each area and weighted averages were computed for certain larger areas which comprise two or more of the subareas. The records prior to 1892 are too meager to afford satisfactory basis for estimating the distribution of precipitation over these areas.

### MONTHLY AND ANNUAL PRECIPITATION.

In Table 6 the averages of the records for the watershed above Grand Forks are shown. The "weighted averages" for 1892 to 1919 were computed by calculating separately the volume of monthly precipitation in each of the five subdivisions of that watershed to find the total volume for the area, and then reducing that quantity to an equivalent depth in inches over the watershed for each month and year.

TABLE 6.—*Average precipitation on Red River watershed above Grand Forks, N. Dak. (compiled from record of U. S. Weather Bureau).*

| Year. | No. of stations. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* |
| 1882 | 3 | 0.81 | 0.65 | 1.84 | 1.68 | 3.49 | 5.40 | 4.92 | 1.31 | 1.03 | 4.05 | 1.42 | 0.76 | 27.36 |
| 1883 | 3 | .55 | .40 | .18 | 1.17 | 2.74 | 1.48 | 2.98 | 3.41 | 1.91 | 3.06 | .17 | .69 | 18.74 |
| 1884 | 3 | .35 | .79 | .74 | 1.10 | 3.05 | 1.93 | 4.75 | 5.87 | 2.45 | 2.83 | .43 | .97 | 25.26 |
| 1885 | 7 | .35 | .15 | .37 | 2.79 | 1.49 | 4.45 | 4.01 | 1.49 | 1.71 | .56 | .93 | .43 | 18.73 |
| 1886 | 7 | .68 | .58 | .41 | 3.21 | 1.85 | 3.00 | 2.91 | 1.47 | 1.67 | 1.40 | 1.17 | .45 | 18.80 |
| 1887 | 8 | .64 | .53 | .46 | 1.70 | 2.18 | 4.42 | 4.48 | 2.58 | 1.34 | 1.45 | .42 | 1.57 | 21.77 |
| 1888 | 8 | .72 | .29 | .91 | 1.21 | 1.69 | 3.92 | 4.21 | 1.42 | .97 | 1.26 | .28 | .21 | 17.09 |
| 1889 | 8 | .81 | .78 | .37 | 1.12 | 1.82 | 1.76 | 2.61 | 2.14 | 2.53 | .07 | .43 | .89 | 15.33 |
| 1890 | 8 | .61 | 1.07 | .65 | .77 | 1.43 | 5.46 | 2.54 | 2.38 | 2.36 | 2.46 | .28 | .25 | 20.26 |
| 1891 | 7 | .43 | 1.21 | 1.21 | 2.99 | 2.00 | 4.61 | 3.99 | 2.64 | 3.01 | 1.59 | .85 | 1.09 | 25.62 |
| 1892 | 14 | .35 | .71 | 1.17 | 3.15 | 4.07 | 3.19 | 3.20 | 2.84 | .70 | .28 | 1.06 | .25 | 20.97 |
| 1893 | 18 | 1.06 | .82 | 1.36 | 2.77 | 1.82 | 3.00 | 3.08 | 2.77 | 1.03 | 1.19 | .50 | 1.05 | 20.45 |
| 1894 | 19 | .46 | .34 | 1.77 | 3.62 | 2.62 | 3.64 | .75 | 1.49 | 1.31 | 2.44 | .37 | .51 | 19.32 |
| 1895 | 17 | .49 | .38 | .10 | 1.44 | 2.16 | 6.34 | 3.32 | 2.14 | 1.32 | .24 | 1.41 | .21 | 19.55 |
| 1896 | 20 | .86 | .67 | 1.35 | *4.94* | *5.17* | 3.35 | 1.69 | 2.13 | 2.58 | 1.73 | *2.33* | .40 | 27.20 |
| 1897 | 20 | 1.22 | 1.46 | 1.23 | .94 | .89 | 5.99 | *6.93* | 1.23 | .68 | 1.19 | .28 | .30 | 22.34 |
| 1898 | 21 | .09 | .55 | .84 | 1.37 | 2.60 | 3.63 | 3.86 | 2.27 | 1.66 | 2.18 | .46 | .29 | 19.80 |
| 1899 | 22 | .51 | .21 | .76 | 1.52 | 4.55 | 3.41 | 2.45 | 3.80 | 1.03 | 1.61 | .42 | .36 | 20.63 |
| 1900 | 22 | .28 | .42 | 1.06 | 1.24 | .83 | 1.47 | 2.90 | *7.40* | *4.52* | 2.78 | .55 | .33 | 23.78 |
| 1901 | 22 | .32 | .51 | 1.25 | 1.85 | .96 | 6.75 | 5.58 | 2.17 | 2.39 | *3.20* | .27 | .77 | 26.02 |
| 1902 | 22 | .20 | .62 | *1.91* | 1.56 | 3.97 | 3.60 | 2.72 | 3.38 | .79 | 2.65 | .44 | .62 | 22.46 |
| 1903 | 23 | .71 | .45 | .73 | 1.60 | 3.12 | 1.31 | 3.24 | 4.35 | 3.36 | 1.81 | .30 | .79 | 21.77 |
| 1904 | 23 | .38 | .91 | 1.66 | 2.31 | 2.15 | 4.60 | 2.64 | 1.53 | 3.06 | 2.00 | .11 | .75 | 22.10 |
| 1905 | 24 | .38 | .25 | .89 | 1.41 | 5.04 | 4.96 | 5.08 | 3.86 | 1.97 | 1.09 | 1.82 | .17 | 26.92 |
| 1906 | 23 | .99 | .17 | .57 | 2.03 | 4.77 | 4.27 | 3.10 | 2.91 | 1.91 | 1.08 | 1.93 | 1.23 | 24.96 |
| 1907 | 23 | 1.26 | .27 | .64 | .97 | 1.56 | 3.96 | 3.09 | 2.62 | 2.41 | 1.07 | .18 | .45 | 18.48 |
| 1908 | 23 | .19 | *1.48* | 1.27 | 1.26 | 3.86 | 3.55 | 2.56 | 3.05 | 1.39 | 1.31 | 1.34 | .58 | 21.84 |
| 1909 | 22 | .60 | .32 | .33 | 1.09 | 4.18 | 3.37 | 4.01 | 3.71 | 1.20 | 1.20 | .72 | *1.52* | 22.25 |
| 1910 | 21 | .29 | .55 | .79 | 1.61 | .79 | 1.53 | 1.65 | 1.32 | 2.14 | .61 | .50 | .43 | 12.21 |
| 1911 | 24 | 1.25 | .75 | .41 | 1.80 | 3.56 | 3.30 | 2.51 | 3.19 | 2.51 | 1.34 | 1.01 | .54 | 22.17 |
| 1912 | 29 | .32 | .20 | .34 | 2.49 | 3.81 | 2.13 | 4.39 | 3.57 | 3.98 | .56 | .14 | .70 | 22.63 |
| 1913 | 29 | .45 | .14 | 1.05 | 1.06 | 1.96 | 2.91 | 3.56 | 2.58 | 2.81 | 2.71 | .22 | .04 | 19.49 |
| 1914 | 33 | .53 | .37 | 1.17 | 2.09 | 2.79 | 7.11 | 3.21 | 2.93 | 1.59 | 1.62 | .43 | .38 | 24.22 |
| 1915 | 35 | .63 | 1.05 | .31 | 1.32 | 3.61 | *7.56* | 2.54 | 1.19 | 2.45 | 1.10 | .72 | .58 | 23.06 |
| 1916 | 36 | *1.57* | .43 | 1.64 | 2.06 | 3.35 | 4.80 | 4.20 | 4.06 | 3.74 | .53 | .09 | 1.29 | *27.76* |
| 1917 | 34 | .70 | .86 | .42 | 1.85 | .27 | 1.97 | 2.02 | 1.21 | 2.27 | 1.02 | .19 | .63 | 13.41 |
| 1918 | 33 | .54 | .19 | .34 | 2.35 | 3.26 | 2.00 | 2.89 | 4.22 | .41 | 1.22 | 1.18 | 1.04 | 19.64 |
| 1919 | 33 | .29 | .66 | .74 | 1.65 | 3.77 | 3.26 | 4.53 | 3.39 | 1.22 | 1.12 | 1.82 | .57 | 23.02 |

NOTE.—Figures show "weighted averages" for 1892 to 1919. Maximums shown in italics.

The maximum annual precipitation over the whole watershed since 1885 occurred in 1896. While slightly greater average annual precipitation was recorded at two observation stations for 1880 and 1882, and a much greater amount for 1878, than is shown for 1896, it is believed the earlier records should not be taken to represent the averages for the whole watershed area, because observations were recorded at but two or three stations. In 1885 the number of stations was increased to seven and these were distributed quite widely over the watershed: so the averages shown in Table 6 for the period subsequent to 1885 are considered more reliable than those for the earlier years.

TABLE 7.—*Maximum, mean, and minimum annual precipitation for subdivisions of the watershed (see fig. 5) for period 1892 to 1919.*

| Watershed. | | Maximum. | | | Mean. | | Minimum. | | |
|---|---|---|---|---|---|---|---|---|---|
| Subdivision. | Area (square miles). | Year. | Depth (inches). | Volume (billions of cubic feet). | Depth (inches). | Volume (billions of cubic feet). | Year. | Depth (inches). | Volume (billions of cubic feet). |
| 1 | 4,225 | 1916 | 35.2 | 345.3 | 24.2 | 238.3 | 1910 | 13.6 | 133.3 |
| 2 | 2,210 | 1906 | 32.5 | 166.6 | 21.8 | 111.5 | 1910 | 13.1 | 67.2 |
| 3 | 9,815 | 1905 | 27.7 | 632.3 | 21.3 | 485.5 | 1910 | 11.4 | 260.2 |
| 4 | 4,185 | 1896 | 22.2 | 215.8 | 17.3 | 168.4 | 1917 | 11.8 | 114.6 |
| 5 | 5,320 | 1896 | 31.6 | 391.1 | 24.0 | 296.9 | 1917 | 12.2 | 151.1 |
| 6 | 6,275 | 1896 | 24.5 | 356.6 | 19.0 | 276.1 | 1917 | 12.1 | 176.1 |
| 7 | 3,865 | 1904 | 25.1 | 225.6 | 17.7 | 158.9 | 1897 | 10.3 | 92.6 |
| 1 and 2 above Fargo and Moorhead | 6,435 | 1916 | 34.2 | 511.9 | 23.4 | 349.8 | 1910 | 13.4 | 200.5 |
| 1 to 5 above Grand Forks. | 25,755 | 1916<br>1896 | 27.8<br>27.2 | 1,661.2<br>1,628.3 | 21.7 | 1,300.6 | 1910 | 12.2 | 730.9 |
| 1 to 7 above international boundary. | 35,895 | 1896<br>1916 | 26.5<br>25.72 | 2,209.8<br>2,144.8 | 20.8 | 1,735.6 | 1910 | 12.3 | 1,029.5 |

Figure 6 shows the amount and distribution of the annual precipitation for 1896, which is the year of greatest precipitation from 1885 to 1919, inclusive. Table 7 shows the maximum, mean, and minimum annual precipitation for the seven subdivisions of the watershed shown in figure 5, also like quantities for the watersheds above Fargo, above Grand Forks, and for the entire area south of the international boundary.

The maximum precipitation over sub-areas 4, 5, and 6 occurred in 1896, the year in which the precipitation was maximum over the whole watershed. In 1916 occurred the maximum on sub-area 1, on subareas 1 and 2 combined (south of Fargo and Moorhead), and on the watershed above Grand Forks which comprises sub-areas 1 to 5, On subarea 2 maximum precipitation occurred in 1906; on No. 3, in 1905; and on No. 7, in 1904. The precipitation on large portions of the watershed during the first six months of 1916, and during the last six months of 1909, was considerably above normal and caused excessive run-off. Figure 7 indicates the total precipitation for these half-year periods. This combination year was used later in computing run-off. The total, however, does not exceed the 1896 precipitation (fig. 6) except on the small area south of Red Lake which was covered by the storm of July 20–22, 1909.

The distribution of the mean annual precipitation for the entire watershed is indicated on figure 8. This map was prepared by plotting the average precipitation at stations having records covering 10 or more years. The maximum and the mean annual precipitation as indicated on figures 6 and 8, respectively, have been greatest in the southeastern portion of the watershed and have diminished in intensity to the west and north.

Average depths of monthly and annual precipitation in the seven subdivisions (see fig. 5) of the watershed for the period 1892 to 1919 were computed. The depths averaged were measured at from 2 to 12 weather observation stations in each sub-area. The total volume of precipitation for maximum months and for months immediately preceding months when run-off above Grand Forks has been maximum are shown in figure 9.

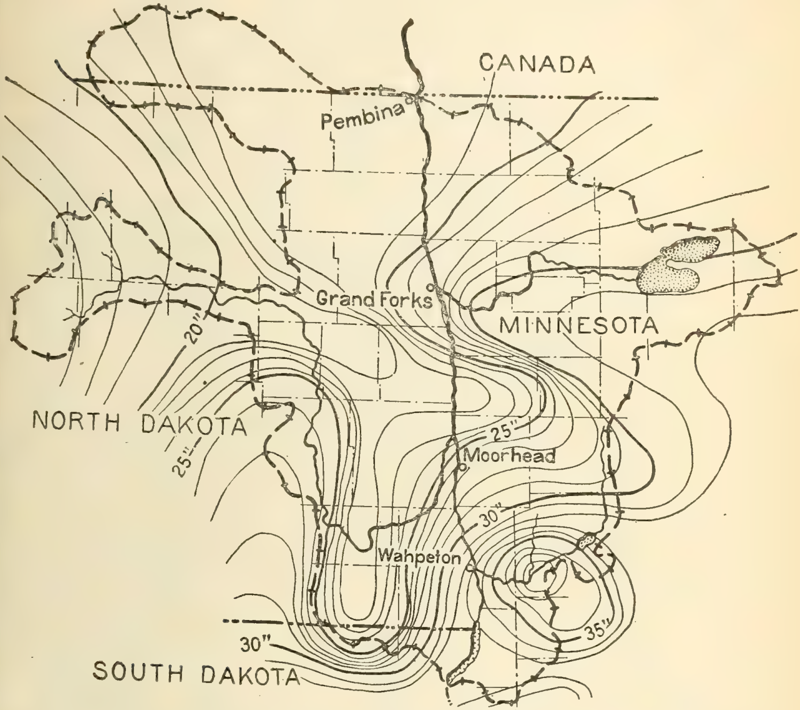

Fig. 6.—Total precipitation during 1896 on watershed of Red River of the North.

As is indicated in the various figures and tables, maximum precipitation for April, May, and November occurred in 1896 when the annual precipitation was maximum. In 1900 occurred the maximums for August and September but the total precipitation for that year was considerably below the maximum. In no case has the maximum for more than one of the remaining seven months occurred in a single year; each has occurred during a year for which the annual precipitation was above the mean for the watershed.

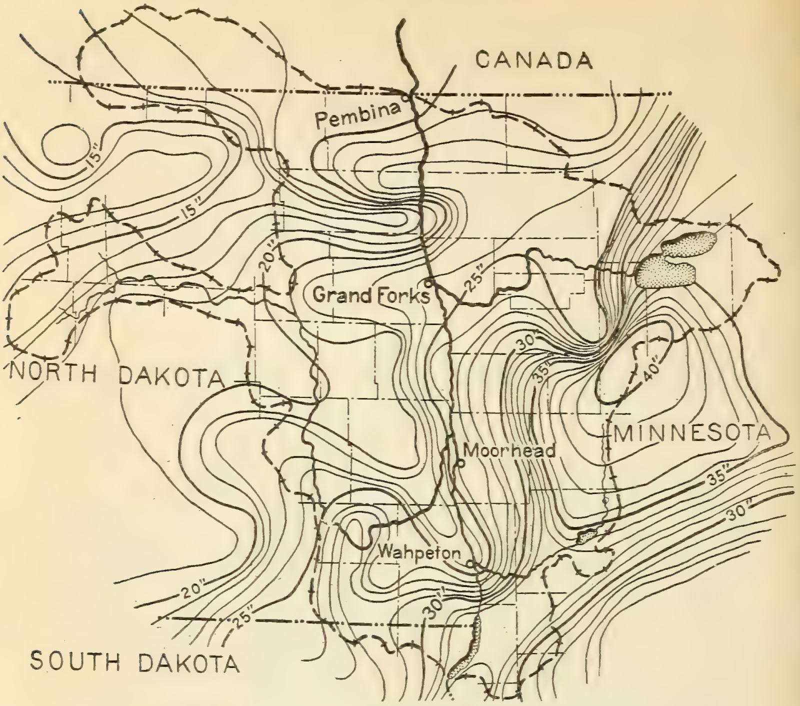

FIG. 7.—Precipitation on watershed of Red River of the North during 12 months comprising January to June, 1916, and July to December, 1909.

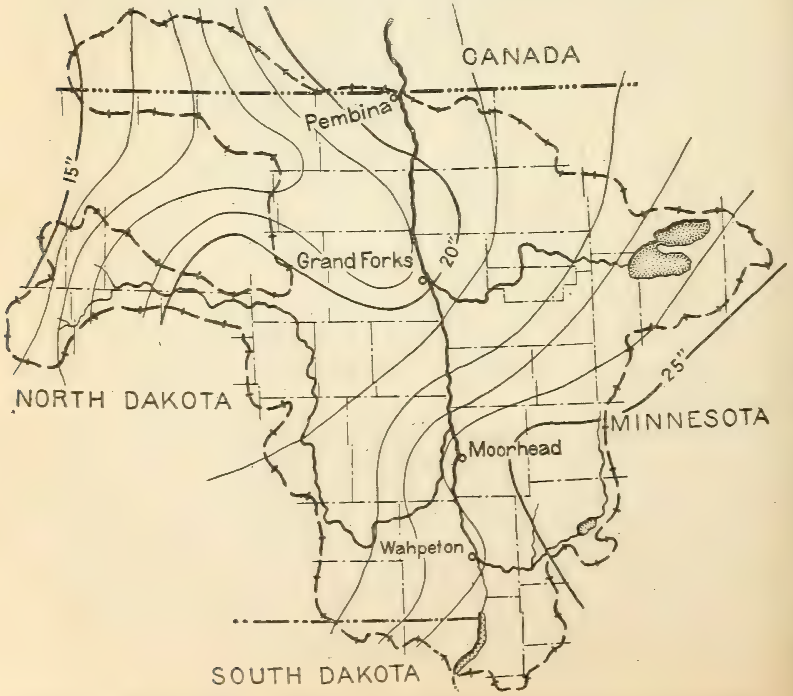

FIG. 8.—Mean annual precipitation on watershed of Red River of the North.

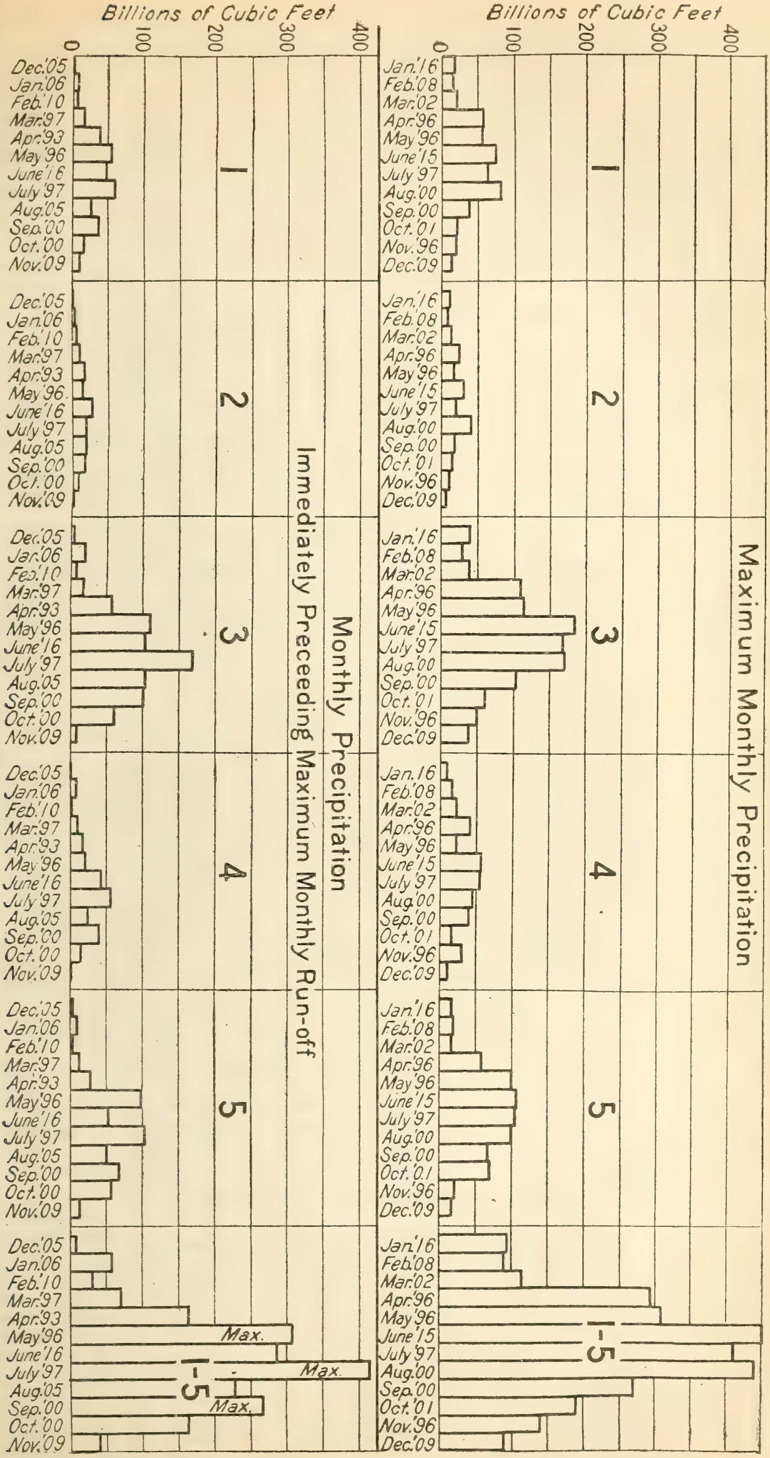

FIG. 9.—Precipitation on five subdivisions of Red River watershed. (See fig. 5.)

A study of the annual and monthly records indicates that no combination of excessive monthly precipitation is likely to occur which will produce a maximum annual precipitation of more than 30 inches over that part of the Red River watershed south of the international boundary. It appears also that the maximum annual precipitation for the extreme western portions of the watershed will probably not exceed 25 inches, and that the maximum for areas of 2,000 square miles or greater in the eastern sections of the watershed will probably not exceed 37 inches. The maximum annual precipitation on the watershed above Fargo and on the Red Lake River watershed above Crookston will probably not exceed 36 inches. From the maximum of 37 inches south of Lake Traverse and 36 inches south of Red Lake intensities diminish toward the north by about 2 inches per degree of latitude, and toward the west by about 3 inches per degree of longitude. These maximum conditions are likely to occur but once in a long period, perhaps 50 to 75 years.

The records further show that maximum annual and monthly precipitation on the smaller watersheds have not occurred simultaneously on the different sub-areas. It is improbable, therefore, that the estimated maximum precipitation will occur on all the sub-areas in any one year.

### STORM PRECIPITATION.

Records were compiled of all storms within the Red River watershed with precipitation of 2 inches or more in 24 hours. For each storm the depths of precipitation for one day, two days, three days, and for the duration of the storm were determined for all observation stations within or near the watershed. The records cover the 26-year period 1894 to 1919, and include 130 storms of from two to eight days' duration (see Table 8). By plotting isohyetals on a map of the Red River watershed the intensity and extent of the storms were made evident. The areas covered by storms during the years 1894 to 1904 are somewhat indefinite, as the number of records is small. For the period 1905 to 1919 many more records are available and the areas covered can be more accurately determined. During many of the storms excessive precipitation occurred in but few localities and covered but small areas. The relative importance of the storms was determined from the isohyetal maps.

TABLE 8.—*Storm periods during which precipitation of 2 inches or more occurred on Red River watershed in the United States.*

| Year. | Date. | Length of storm period. | Year. | Date. | Length of storm period. |
|---|---|---|---|---|---|
| | | *Days.* | | | *Days.* |
| 1894 | Apr. 15–20 | 6 | 1896 | Mar. 4–7 | 4 |
| | June 26–28 | 3 | | Apr. 8–13 | 6 |
| 1895 | June 2–5 | 4 | | Apr. 25–30 | 6 |
| | June 6–10 | 5 | | May 11–17 | 7 |
| | July 4–8 | 5 | | June 4–8 | 5 |

TABLE 8.—*Storm periods during which precipitation of 2 inches or more occurred on Red River watershed in the United States*—Continued.

| Year. | Date. | Length of storm period. | Year. | Date. | Length of storm perion. |
|---|---|---|---|---|---|
| | | *Days.* | | | *Days.* |
| 1897 | June 1-3 | 3 | 1905 | July 3-5 | 3 |
| | June 14-19 | 6 | | Aug. 13-17 | 5 |
| | June 27-29 | 3 | 1906 | May 23-26 | 4 |
| | July 1-4 | 4 | | June 6-9 | 4 |
| | July 6-9 | 4 | | June 17-21 | 5 |
| | July 17-22 | 6 | | July 31-Aug. 2 | 3 |
| 1898 | Apr. 29-May 1 | 3 | | Aug. 20-25 | 6 |
| | May 17-22 | 6 | | Sept. 11-16 | 6 |
| | June 21-27 | 7 | 1907 | June 9-11 | 3 |
| | June 30-July 2 | 3 | | Aug. 4-5 | 3 |
| | Aug. 21-23 | 3 | | Aug. 26-28 | 3 |
| 1899 | May 26-31 | 6 | 1908 | June 5-8 | 4 |
| | June 1-6 | 6 | | June 17-19 | 3 |
| | June 10-14 | 5 | | June 21-24 | 4 |
| | July 2-6 | 5 | | Aug. 26-31 | 6 |
| | Aug. 6-11 | 6 | 1909 | May 29-June 1 | 4 |
| | Aug. 15-20 | 6 | | July 11-14 | 4 |
| 1900 | Apr. 23-29 | 7 | | July 19-21 | 3 |
| | July 1-7 | 7 | | Aug. 6-8 | 3 |
| | Aug. 4-11 | 8 | | Aug. 10-13 | 4 |
| | Aug. 19-25 | 7 | 1910 | Apr. 14-18 | 5 |
| | Sept. 4-5 | 2 | | July 22-24 | 3 |
| | Sept. 8-11 | 4 | | Sept. 4-6 | 3 |
| | Sept. 14-15 | 2 | 1911 | May 9-12 | 4 |
| | Sept. 23-25 | 3 | | May 14-16 | 3 |
| 1901 | June 9-12 | 4 | | June 1-4 | 4 |
| | June 14-16 | 3 | | July 22-24 | 3 |
| | June 20-25 | 6 | | Sept. 4-7 | 4 |
| | July 2-5 | 4 | 1912 | Apr. 12-15 | 4 |
| | July 23-28 | 6 | | May 2-5 | 4 |
| | Sept. 10-14 | 5 | | June 13-16 | 4 |
| | Oct. 5-9 | 4 | | July 26-28 | 3 |
| 1902 | Mar. 23-27 | 5 | 1913 | July 2-5 | 4 |
| | Apr. 21-22 | 2 | | Aug. 17-21 | 5 |
| | May 1-3 | 3 | | Sept. 9-11 | 3 |
| | May 15-21 | 7 | | Oct. 4-6 | 3 |
| | June 5-7 | 3 | 1914 | Apr. 26-28 | 3 |
| | July 4-6 | 3 | | June 4-9 | 6 |
| | July 28-30 | 3 | | June 26-27 | 2 |
| | Aug. 27-31 | 5 | | July 21-22 | 2 |
| | Oct. 23-26 | 4 | | Sept. 12-14 | 3 |
| 1903 | May 19-23 | 5 | | Oct. 8-12 | 5 |
| | June 29-July 4 | 6 | 1915 | June 10-13 | 4 |
| | July 26-28 | 3 | | June 26-28 | 3 |
| | Aug. 26-28 | 3 | 1916 | Apr. 18-21 | 4 |
| | Sept. 11-13 | 3 | | May 13-16 | 4 |
| | Oct. 2-4 | 3 | | June 28-30 | 3 |
| 1904 | Apr. 7-10 | 4 | | Sept. 9-10 | 2 |
| | May 11-13 | 3 | 1917 | June 4-8 | 5 |
| | June 2-5 | 4 | | June 10-13 | 4 |
| | June 8-10 | 3 | | July 4-6 | 3 |
| | June 22-25 | 4 | | Sept. 18-20 | 3 |
| | July 2-4 | 3 | 1918 | Apr. 16-22 | 7 |
| | July 13-14 | 2 | | Apr. 26-29 | 4 |
| | Aug. 17-22 | 5 | | May 18-21 | 4 |
| | Aug. 30-Sept. 3 | 5 | | May 29-June 1 | 4 |
| 1905 | May 2-5 | 4 | | July 24-28 | 5 |
| | May 9-12 | 4 | | Aug. 16-22 | 7 |
| | June 3-6 | 4 | 1919 | June 20-23 | 4 |
| | June 23-25 | 3 | | July 1-4 | 4 |

*Summary.*

| Length of storm period (days). | Number of storms, 1894 to 1919. | | | | | | | | Total. |
|---|---|---|---|---|---|---|---|---|---|
| | March. | April. | May. | June. | July. | August. | September. | October. | |
| 2 | | 1 | | 1 | 2 | | 3 | | 7 |
| 3 | | 2 | 3 | 12 | 11 | 5 | 6 | 2 | 41 |
| 4 | 1 | 4 | 9 | 13 | 6 | 1 | 2 | 2 | 38 |
| 5 | 1 | 1 | 1 | 5 | 3 | 4 | 2 | 1 | 18 |
| 6 | | 3 | 2 | 5 | 2 | 4 | 1 | | 17 |
| 7 | | 2 | 2 | 1 | 1 | 2 | | | 8 |
| 8 | | | | | | 1 | | | 1 |
| Total | 2 | 13 | 17 | 37 | 25 | 17 | 14 | 5 | 130 |

From the 130 storms 13 were selected for which the precipitation was exceptionally heavy over considerable area. The date, duration, and location of each storm and amount of precipitation at one station are shown in chronological order in Table 9. Three storms of maximum intensity for areas which vary in size from 300 to 35,000 square miles were selected for more detailed study. Depth-area curves for these three storms are shown in figure 10. The run-off resulting from each of these three storms was measured at stream gaging stations at one or more points in the watershed.

TABLE 9.—*Storm precipitation on Red River watershed in the United States.*

| Year. | Date. | Length of storm period. | Total precipitation at center of storm. | Location of storm center. | Maximum 24-hour precipitation at one observing station. |
|---|---|---|---|---|---|
| | | *Days.* | *Inches.* | | *Inches.* |
| 1897 | June 27–29 | 3 | 4.66 | Amenia, N. Dak | 2.35 |
| 1897 | July 17–22 | 6 | 7.42 | Wild Rice, N. Dak | 5.86 |
| 1899 | Aug. 17–20 | 4 | 8.18 | Leech Lake, Minn | 4.31 |
| 1900 | Aug. 4–11 | 8 | 10.50 | Alexandria, Minn | 3.15 |
| 1908 | Aug. 26–31 | 6 | 6.93 | Crookston, Minn | 5.85 |
| 1909 | July 20–22 | 3 | 11.10 | Beaulieu, Minn | 10.75 |
| 1915 | June 10–13 | 4 | 3.91 | Detroit, Minn | 2.75 |
| 1915 | June 26–28 | 3 | 5.04 | Mayville, N. Dak | 3.98 |
| 1916 | Apr. 18–21 | 4 | 2.58 | Campbell, Minn | 2.26 |
| 1916 | May 13–16 | 4 | 3.34 | Fullerton, N. Dak | 2.94 |
| 1916 | June 28–30 | 3 | 3.84 | Beardsley, Minn | 3.67 |
| 1919 | June 20–23 | 4 | 6.13 | Cando, N. Dak | 5.30 |
| 1919 | July 1–4 | 4 | 9.02 | Warroad, Minn | 4.92 |

The storm of July 17–22, 1897, covered the entire Red River watershed. The precipitation was the maximum of record during any storm covering the entire watershed and was maximum for any portion of the watershed 8,000 to 35,000 square miles in area. Isohyetals for the storm are shown in figure 11. Following this storm there occurred the highest stage of record at Grand Forks for July and August, and the total discharge of the river for August, 1897, was the recorded maximum for August. Less than a month earlier than the July storm (June 27–29) another storm had occurred which may have increased the run-off after July 17 in certain localities.

During the storm of July 1 to 4, 1919, precipitation was the maximum that has been recorded on areas of 2,000 to 8,000 square miles within the Red River basin. Isohyetals for this storm are shown in figure 12. This storm produced very high stages on Red Lake River, Thief River, Clearwater River, Roseau River, and Two Rivers, and caused heavy losses from drowned crops in eastern Marshall County and in Roseau County, Minn. Nine inches of rain fell in four days over an area of approximately 390 square miles.

The maximum storm precipitation that has been recorded for areas of 300 to 2,000 square miles occurred on July 20–22, 1909 (see fig. 13). The maximum 24-hour precipitation recorded for one station was 10.75 inches. Besides being maximum for the Red River Valley this storm, according to investigations made by the Miami (Ohio) Conservancy District, was one of the greatest that occurred in the upper Mississippi Valley during the period 1892–1916 and was the only one of 49 great storms in the northern portion of central and eastern United States that shows a precipitation in excess of 6 inches in 3 days over a considerable area in the Red River watershed. This storm was central over the watershed of the Wild Rice River in Minnesota and caused a more intense run-off to reach Twin Valley, Minn., than has been recorded on any other watershed of similar size (835 square miles) in the Red River basin. This storm precipitation so far exceeded any other that has been recorded in the Red River Valley that it is doubtful whether any as intense as that will occur again within 75 or 100 years on an area of 800 square miles anywhere in the valley.

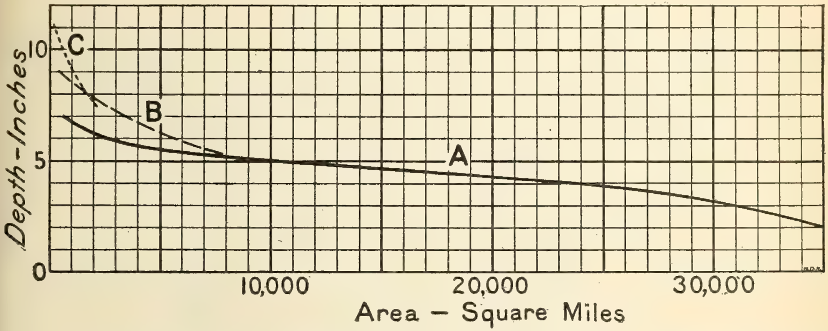

FIG. 10.—Depth-area curves for maximum storm precipitation on watershed of Red River of the North. A, Storm of July 17–22, 1897; B, storm of July 1–4, 1919; C, storm of July 20–22, 1909.

Relative to the other 10 storms listed in Table 9, the records for several are of special importance. In some cases the heavy precipitation covered areas from which the run-off was measured, while areas covered by some were outside the watershed to the east and southeast and no measurements were made. The storm of June 20–23, 1919, was central over Towner County, N. Dak. It was unusual in that the heaviest precipitation occurred in the northwestern section of the Red River watershed. The maximum 4-day precipitation was slightly more than 6 inches but that intensity occurred over a comparatively small area. This storm, however, caused heavy precipitation over the Lake Traverse watershed. The records are meager but apparently on that area the rainfall was from 2½ to 4 inches in

48 hours. The run-off from this storm raised the water in Lake Traverse approximately 2 feet but did not materially increase the discharge from the lake.

The effect of the two storms of June 10–13 and June 26–28, 1915 (fig. 14), is quite marked in the run-off records of Red River at Fargo, Grand Forks, and Emerson. The monthly precipitation for June of that year was maximum. Apparently this was largely due to these two storms which covered large areas in the central portion of the watershed above Grand Forks. The run-off for the following month was very close to maximum at that station. Investigation of the monthly and storm precipitation data (see Table 8, Summary) showed that one or more storms occurred during each month March to September, inclusive, and that the excessive monthly precipitation of this period was due largely to excessive storms.

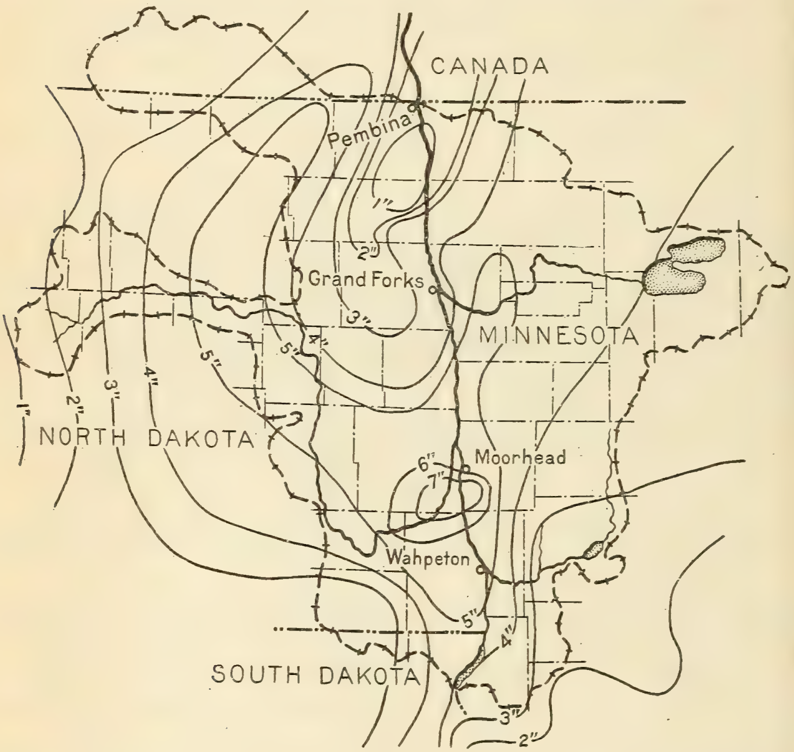

Fig. 11.—Maximum 6-day storm rainfall on watershed of Red River of the North, July 17–22, 1897.

In the period 1894–1919 excessive storm precipitation, causing maximum or nearly maximum monthly precipitation, occurred during each month just prior to the months from May to October for which the run-off was maximum above Grand Forks. Thus May, 1896, July, 1897, and September, 1900, months of maximum precipitation, were followed by months of maximum run-off, June, August, and October, respectively. Again during May, 1896, and May, 1904, the run-off was near the May maximum for the period 1894 to 1919, because of storms in April and the first half of May in each of those years.

Maximum run-off during July, 1916, at Grand Forks was due to excessive storm precipitation in June and to heavy monthly precipitation (approaching maximum) for June and July. Maximum run-off during September, 1905, was due largely to heavy storm precipitation during the last half of August over the central portion of the watershed.

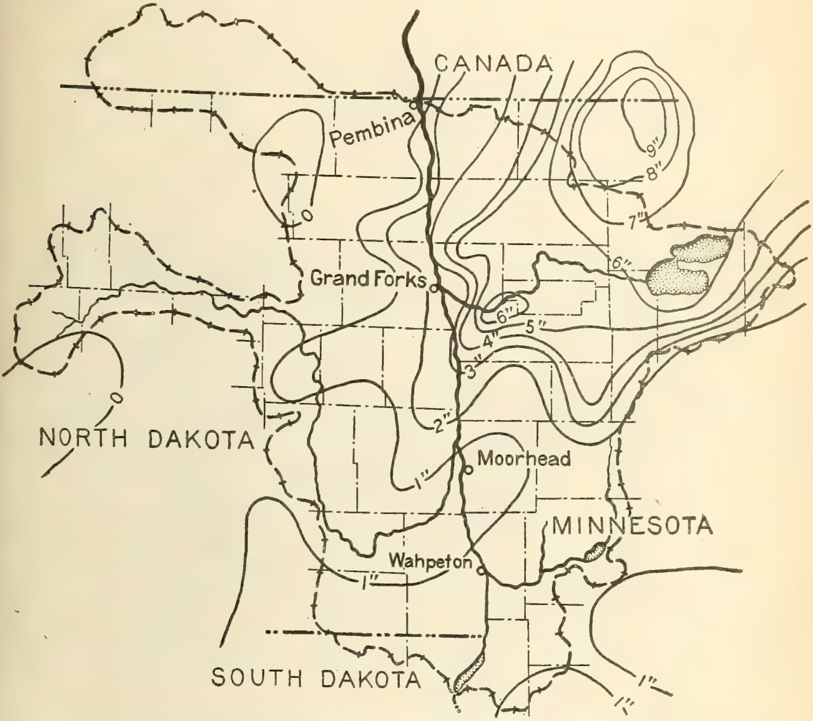

FIG. 12.—Maximum 4-day storm rainfall on watershed of Red River of the North, July 1–4, 1919.

Thus it appears that maximum monthly precipitation due largely to excessive storm precipitation over a considerable portion of the Red River watershed, during the months April to October, has materially increased the run-off from the watershed; however, maximum monthly precipitation may produce in the following month run-off approaching maximum even though no maximum storm precipitation occurs.

## SNOW.

In the Red River Valley snow has an important effect on run-off during March and April. Snow accumulates in varying quantities during parts or all of the months of November to March, inclusive. The run-off resulting from this stored precipitation was studied for the period for which data were available, 1893 to 1920, inclusive. Weather Bureau records of snow and ice conditions, showing the amount of stored snow remaining on the ground each week from December to March, inclusive, were summarized and are shown in figure 15. It was found that when a considerable portion of the watershed was covered with snow to a depth exceeding 15 inches during the winter, and when near March 1, 12 inches or more of snow remained on the watershed, high stages would occur in the principal streams. In 1893, 1897, 1904, 1907, 1916, and 1920, when flood stages occurred, this relation was found to be true. The only exception was 1917, when the Red River did not quite reach flood stage, although there was quite a heavy snow covering on the watershed (see fig. 15). On March 1, 1920, the snow was from 6 inches to 15 inches in depth (average about 10 inches); this snow melted rapidly during the first half of March and the run-off therefrom

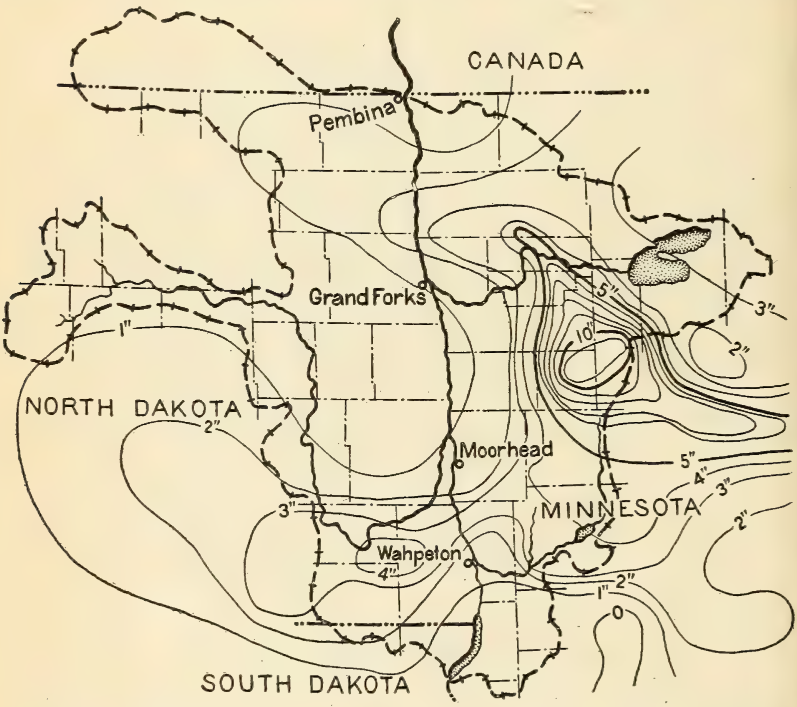

FIG. 13.—Maximnm 3-day storm rainfall on watershed of Red River of the North, July 20–22, 1909.

caused comparatively high stages of the Red River during the last week in March and the first week in April. This investigation showed for the highest flood of which we have record (that of April, 1897) that just prior to the spring break-up the average depth of snow over the watershed was 26 inches, and that all of this snow melted in approximately 20 days. The data also showed that all of the larger floods that have occurred on the Red River have been due mainly to the melting of snow over the watershed, rather than to precipitation at the time the flood occurred, though in some cases precipitation at the time the snow was melting has undoubtedly caused stages somewhat higher than otherwise would have occurred. That rains in April prolong the flood period is indicated by the diagrams for 1904 and 1916, figure 15.

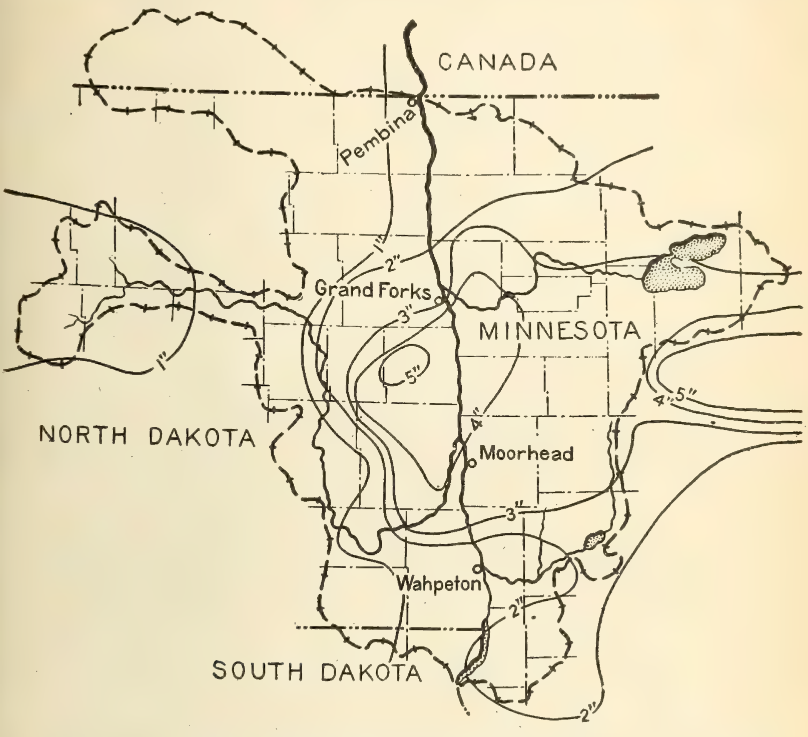

FIG. 14.—Storm rainfall on watershed of Red River of the North, June 26–28, 1915.

Records show that nearly every year more than 25 per cent of the annual run-off occurs in April, although the precipitation for April is seldom excessive and usually is less than 10 per cent of the annual precipitation. This high percentage of run-off during April is due to the melting of the snow stored throughout the winter months and to the more or less impervious condition of the ground at the time of the spring thaw.

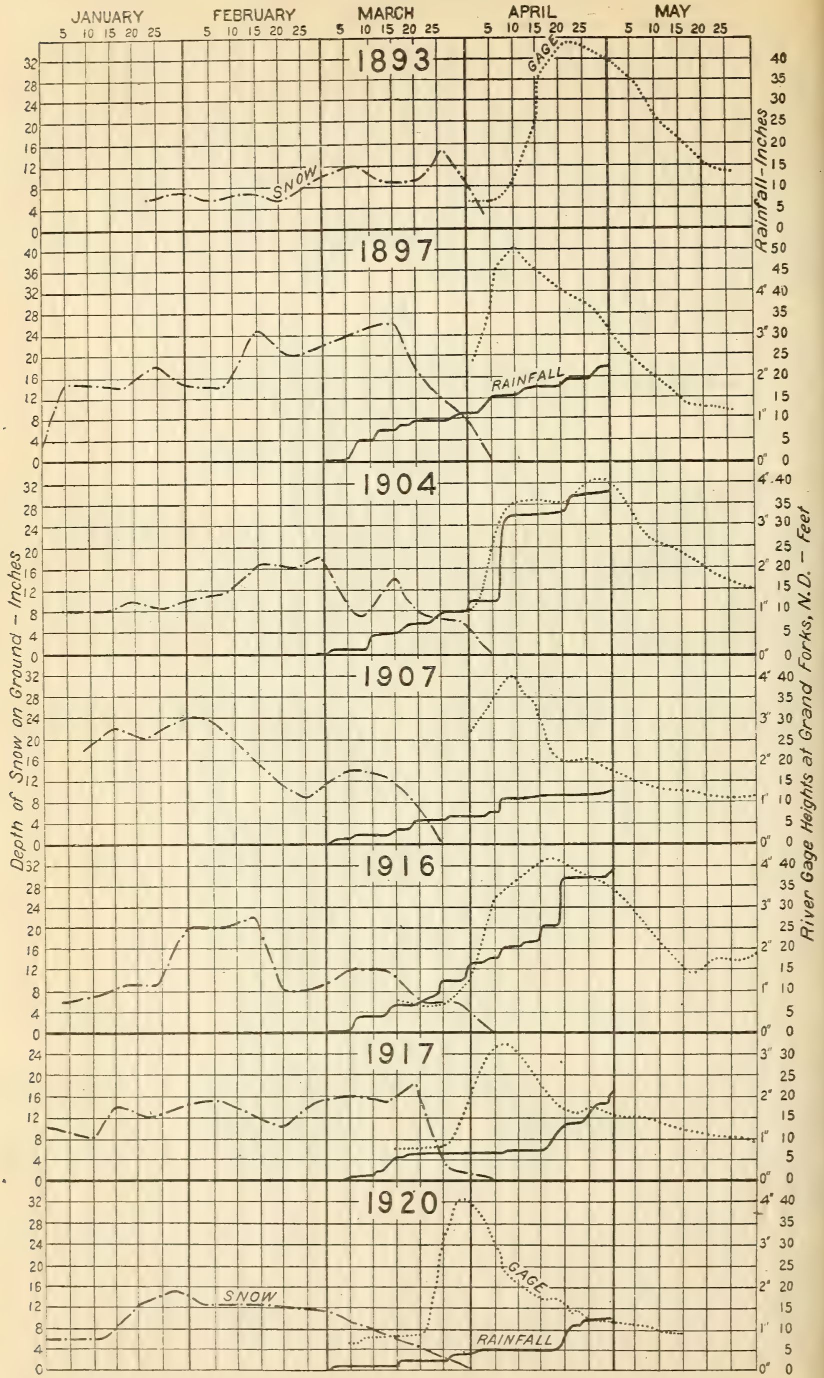

FIG. 15.—Average depth of snow and rainfall over watershed, and stages of Red River of the North at Grand Rapids, N. Dak., for years when floods occurred.

## OTHER FACTORS AFFECTING RUN-OFF.

### TOPOGRAPHY.

Some of the main topographic features have been described. The general topography of the various watersheds is indicated in figure 1; areas are given in Table 1.

In the great central portion of the watershed comprising the area termed "the valley," the surface is nearly level. The run-off there never is rapid. In the highest portions, comprising the areas draining to the upper parts of the tributary streams, large areas are flat and nearly level while others are somewhat rough. Depressions of every size are numerous; some are lakes while others are merely marshy spots and "pot holes." The run-off there is even more slow than in the valley unless it is modified by artificial drainage to carry water from the flat areas and depressions. Between the two portions of the watershed just described is located the area just outside the most recent shore lines of the ancient glacial lake, Agassiz. Here the surface slopes are steeper and comparatively regular and vary from a few feet to 25 or even 50 feet per mile. Much of this area is well drained naturally. The run-off from it is more rapid than from other parts of the watershed, but even here it could hardly be termed "quick." Considering the area as a unit, probably on no other watershed of equal size within the United States is the effect of the topography on run-off more nearly uniform over the whole area.

### SIZE AND SHAPE OF THE WATERSHED AREAS.

The size of a watershed area is the principal factor to be considered in determining the volume of run-off originating on the area, for, approximately speaking, volume of run-off varies directly with the size of watershed. This relation, however, does not hold as between size of watershed and rate of run-off, as the rate of run-off per unit of area decreases as the size of watershed increases. This is true because the most intense storm precipitation and the most rapid melting of snow occur on relatively small areas, and the time of occurrence of the maximum rates of run-off from these separate small drainage areas is seldom, if ever, such as to concentrate these maximum discharges in the main outlet. The relation of size of drainage area to rate of run-off per square mile for various areas in the Red River watershed is indicated in Table 5.

The shape of the watershed of the Red River tends to produce quick run-off. As the width of the area nearly equals its length, the run-off from large portions of the watershed tends to concentrate at certain points. The same conditions are found in many subdivisions of the watershed, as for example the area above Grand Forks, that above Fargo, and watersheds of tributaries as follows: The

Bois de Sioux above Wahpeton, the Buffalo River, the Goose River, the Red Lake River above Crookston, Two Rivers, and the Minnesota Wild Rice River above Twin Valley. On certain other tributary streams where the ratio of width to length is small, the shape tends to prevent a concentration of water in the lower reaches since the water from lower part runs off before that from the upper portion reaches the main stream. On such streams the period of storm run-off is prolonged, but the rate of discharge is not so high as from equal areas where breadth and length are approximately the same. The Sheyenne River is the largest tributary having a long, narrow watershed. The Otter Tail, Sand Hill, and Pembina watersheds are also of this type.

### TEMPERATURE.

The relation between prevailing temperature and precipitation and run-off was studied in some detail. As has been noted previously a large amount of precipitation accumulates on the ground in the form of snow. In the spring, owing to the rise in temperature which may sometimes be accompanied by rain, this accumulation is suddenly carried into the tributaries thus causing maximum floods. The relation which temperature bears to the magnitude of the spring flood depends on, (1) the rate and the amount of the temperature changes; (2) whether the temperature rise occurs simultaneously over the whole or large portions of the valley, or progresses from the upper to the lower portion of the watershed. Since the Red River flows north, if snow covers large portions of the watershed a rise in temperature that moves gradually northward will tend to cause a greater flood than will a simultaneous temperature rise in all parts of the area. Temperature is an important factor as affecting evaporation, and evaporation limits run-off quantities very materially.

In the spring of 1897 when occurred the greatest flood for which reliable records are available, there was a snow covering on March 15 of approximately 26 inches. The temperature rose slowly between March 14 and March 25; after March 25 the temperature rose rapidly and by April 5 the snow had disappeared. On April 10 the maximum flood stage occurred at Grand Forks. There was very little rainfall in the last 10 days in March, approximately one-half inch in the first five days in April, and the precipitation for April was only one-half the normal. High temperature and the warm rains melted the deep snow covering and caused the surface water to move so quickly into the streams that the amount which percolated into the soil probably was comparatively small and opportunity for loss by evaporation was limited. In a similar manner rapid rise in temperature occurring simultaneously over central and northern portions of the valley in 1904 and 1916 produced higher stages than otherwise would have prevailed in the streams.

### VEGETAL COVER.

On areas having moderate slopes such as are found in practically all parts of the Red River watershed, vegetation such as small grains, grasses, potatoes, or other plants whose stalks or leaves form a more-or-less intricate mass through which run-off must pass, tends to decrease run-off. The velocity of flow is retarded by the obstructions thus offered and the time during which evaporation, absorption by the soil, and transpiration of plants may occur is increased. This retarding effect would be greatest from June to September when plant growth is most luxuriant, and would be relatively small during March, April, and part of May, before plants are high enough to obstruct surface flow.

### ARTIFICIAL DRAINAGE.

The function of artificial drainage is the disposal of excess water. Usually it is essential that such water be removed more quickly than it flows off through natural channels. This fact in itself would seem to imply an increased run-off rate as a result of artificial drainage. The drainage, by means of open ditches, of areas which have served as natural reservoirs—such as permanent swamps, marshes, ponds, and lakes—removes large quantities of excess water during the initial period of the operation of the drains. After drains have been in operation for a time the amount of discharge is diminished by whatever water is absorbed by the drained soil and by whatever amount evaporation and transpiration are increased. One effect of tile drainage is similar to that just stated, the run-off being decreased by whatever amount soil absorption is increased by the action of the tile. However, the influence of tile on run-off will develop gradually and appreciable effects will be long delayed because the installation of such drains will proceed slowly.

Artificial drainage may increase the rate of run-off by increasing the number of outlets and thereby shortening the time period during which run-off occurs. However, the decrease in run-off due to increased absorption by the drained soil may more than compensate for the extra outlets.

The only important conclusion which has been reached relative to the effect of artificial drainage on run-off is, that when heavy rainfall occurs or when large quantities of snow melt rapidly, artificial drains may operate to increase the rate of run-off when areas drained are for any reason impervious to water, that is, when the ground is frozen or is saturated. Such increase in rate of run-off will increase flood heights along watercourses of insufficient capacity. Observations seem to indicate, however, that in the Red River valley open drains do not materially increase run-off caused by melting snows in the spring, because a large majority of drains are completely filled or badly obstructed by snow and ice and do not begin to function until several days after the snow on the watershed has melted. Under such conditions run-off collects and flows in natural depressions or channels without being affected to any considerable extent by artificial drainage.

### EVAPORATION AND TRANSPIRATION.

By far the greater part (between 85 and 98 per cent) of precipitation on the Red River watershed is disposed of by evaporation and plant transpiration. As run-off comprises only the remainder of the precipitation those processes largely govern total run-off. Large quantities of water evaporate from the soil and from water and snow surfaces. Annual evaporation from the soil has not been determined definitely but under ordinary conditions this alone is probably as great as annual run-off. The process, however, goes on at a much slower—although more uniform—rate than does run-off, so its relative effect is small when the run-off rate is high.

The rate of evaporation from shallow water near Grand Forks has been measured and recorded by Prof. E. F. Chandler for the period 1905 to 1914. The results have been used in computing the probable evaporation from lakes and reservoirs. Table 10 shows the mean monthly evaporation and the mean monthly temperature for the period 1905–1914.

TABLE 10. *Mean monthly temperature and evaporation at University (near Grand Forks), N. Dak.*

| Month. | Mean temperature. | Mean evaporation. | |
|---|---|---|---|
| | *° F.* | *Inches.* | *Billions of cu. ft. per sq. mi.* |
| January | 4.0 | 0.40 | 0.0009 |
| February | 7.3 | .60 | .0014 |
| March | 22.8 | 1.20 | .0028 |
| April | 44.5 | 3.22 | .0075 |
| May | 52.1 | 4.12 | .0095 |
| June | 65.0 | 4.94 | .0114 |
| July | 67.5 | 5.78 | .0134 |
| August | 65.5 | 4.60 | .0107 |
| September | 57.7 | 3.63 | .0084 |
| October | 45.9 | 2.11 | .0049 |
| November | 27.6 | .63 | .0015 |
| December | 11.3 | .40 | .0009 |

The evaporation figures for April to November, inclusive, are results of observations by Prof. E. F. Chandler, 1905 to 1914; those for December to March are estimates made from available data relating to evaporation during winter months.

The figures deduced by Meyer,[5] as to evaporation from snow and ice, agree very closely with the results of observations made by

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[5] The Elements of Hydrology, Adolph F. Meyer.

Horton.[6] These authorities show that evaporation as high as 2.2 inches may occur during a month just before the snow and ice is changed into water. Snow melting slowly is subject to greater evaporation than snow melting more rapidly because of rains or high atmospheric temperatures.

### ABSORPTION AND STORAGE.

Absorption by the soil, which is in effect a storage of water, affects run-off in two ways. In retarding the escape of water it decreases the rate of run-off by increasing the time required for water to reach drainage outlets, and the amount of run-off by increasing opportunity for evaporation and plant transpiration. Percolation also tends to reduce run-off in much the same manner as does absorption. In the spring the amount of percolation depends upon the condition of the ground when thaw begins. It has been found where the ground, even if frozen, is not saturated, and where water or slush covers it for a time, that a surprisingly large amount of water will seep away. Thus the percolation factor, the dryness of the ground, and the depth to which it was frozen before being covered with snow may affect run-off very materially.

The effect of storage in lakes, ponds, and reservoirs is similar to that of storage by soil absorption. The stored water is delayed in reaching drainage outlets, and thus greater opportunities for evaporation and transpiration are afforded.

### RELATION BETWEEN PRECIPITATION AND RUN-OFF.

For each of those watershed areas on which precipitation and run-off records are coextensive the probable effect of extreme precipitation conditions was determined. Moreover, various relations which are more or less indefinite were indicated by data compiled. Thus certain data on precipitation were adapted for use to a limited extent in connection with other data in estimating run-off for all the watershed areas listed in Table 5. As the run-off records for the watershed above Grand Forks cover a much longer period than is covered by records for any other area the relation of precipitation to run-off was investigated in considerable detail for that watershed.

### ANNUAL AND MONTHLY PRECIPITATION AND RUN-OFF.

For the period 1882 to date annual and monthly precipitation records are available for all the watershed areas on which records have been kept of the run-off. On four watersheds, namely, Red River above Grand Forks, Red River above Fargo, Red Lake River above Crookston, and Thief River above Thief River Falls, the ratio of annual run-off to annual precipitation was computed. The data for the area above Grand Forks are shown in figure 16. On that watershed the run-off in 1897 was maximum both in depth (3.2 inches) and in percentage of annual precipitation (14.3 per cent). In 1916, when maximum recorded annual precipitation occurred, the run-off (3.1 inches) was nearly maximum, but the percentage of precipitation (11.2 per cent) that appeared as run-off was less than for 1897. The run-off during 1897 was increased by the heavy precipitation of 1896, by maximum depth of snow on the ground in March, 1897, and by extremely heavy monthly and storm precipitation during July, 1897.

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[6] Monthly Weather Review, U. S. Department of Agriculture, February, 1914.

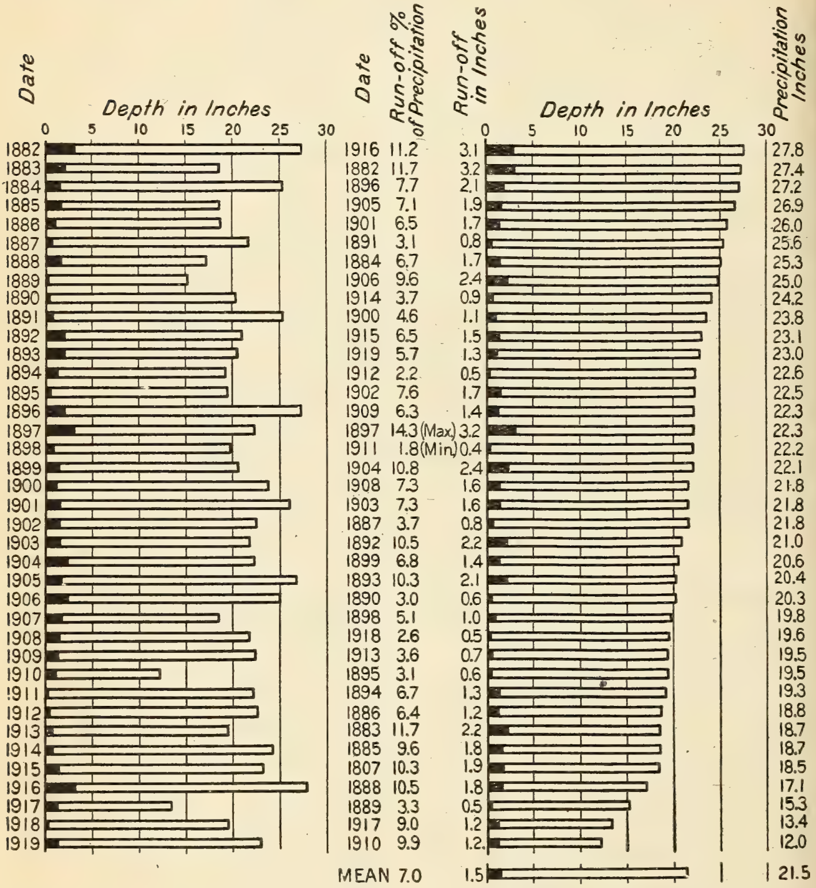

FIG. 16.—Annual precipitation and run-off on Red River of the North watershed above Grand Forks, N. Dak.

Probable future maximum run-off as estimated from a study of all available data for the four watersheds mentioned above is indicated in Table 11. It is improbable, however, that run-off equivalent to the percentages shown in the table will occur during any year when annual precipitation is maximum in depth.

TABLE 11.—*Probable maximum annual run-off.*

| Streams. | Station. | Drainage area. | Ratio of annual run-off to annual precipitation. |
|---|---|---|---|
| | | *Sq. mi.* | *Per cent.* |
| Red River | Grand Forks, N. Dak | 25,755 | 15 |
| Do | Fargo, N. Dak | 6,435 | 15 |
| Red Lake River | Crookston, Minn | 5,320 | 25 |
| Thief River | Thief River Falls, Minn | 1,080 | 25 |

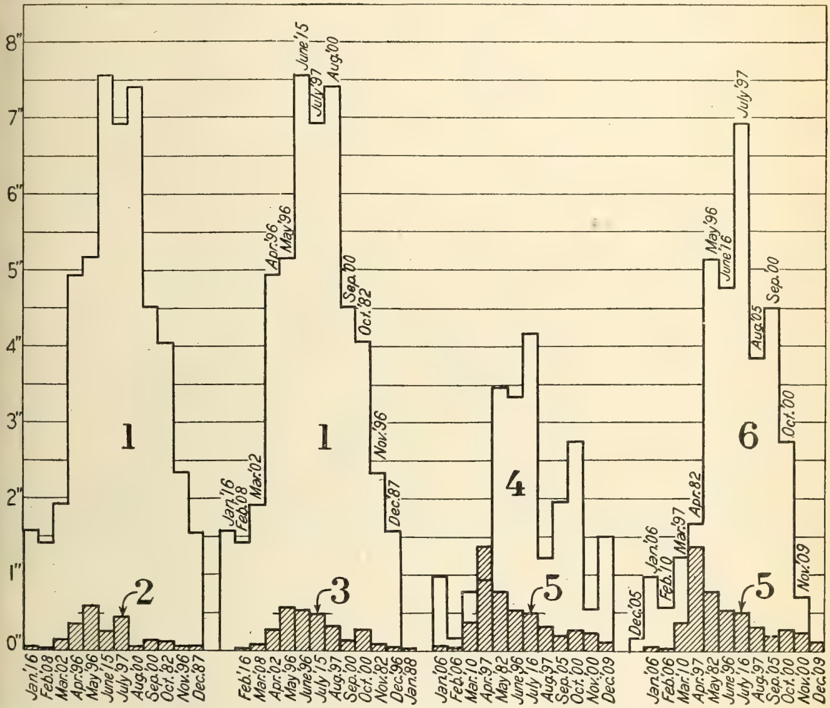

FIG. 17.—Precipitation and run-off, Red River of the North watershed above Grand Forks, N. Dak., for selected months, 1882–1919. 1, Maximum monthly precipitation; 2, run-off during months of maximum precipitation; 3, monthly run-off immediately following maximum monthly precipitation; 4, precipitation during months of maximum run-off; 5, maximum monthly run-off; 6, monthly precipitation immediately preceding maximum monthly run-off.

Investigation shows conclusively that run-off can not be determined by considering it merely as a fixed percentage of precipitation. The part of precipitation that supplies demands of evaporation and plant transpiration is much greater and is more nearly uniform in quantity from year to year than is the part that goes into run-off. For the watershed above Grand Forks, comparisons of annual run-off and annual precipitation are shown in figure 16. Monthly distribution of precipitation and run-off are shown in Tables 6 and 4. During the period 1882 to 1919, maximum monthly precipitation occurred 8 times in May, 13 times in June, 11 times in July, 5 times in August, and once in September. Maximum precipitation for a single month during the 38-year period occurred in June, 1915. June is recorded also as the month having the highest mean monthly precipitation during the period. For this same period the maximum monthly run-off occurred once in March, 24 times in April, 4 times in May, 3 times in June, 4 times in July, once in August, and once in October. Maximum run-off during a single month occurred in April, 1897, while the month having the highest mean monthly run-off for the period also is April. Thus the records show June to be the month of greatest precipitation, and April the month of greatest run-off.

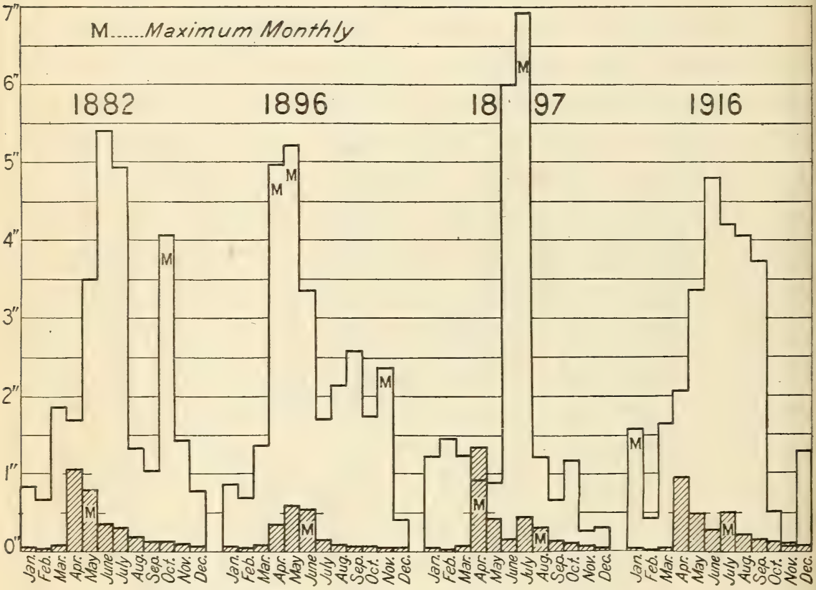

FIG. 18.—Monthly precipitation and run-off, Red River of the North watershed above Grand Forks, N. Dak., for 1882, 1896, 1897, and 1916.

Various combinations of maximum monthly precipitation and run-off as recorded for the watershed above Grand Forks for the period 1882 to 1919, are shown in figure 17. Quantities of a similar kind for 1882, 1896, 1897, and 1916 are shown in figure 18. These diagrams indicate that during the period of April to November, inclusive, excessive monthly precipitation tends to produce high run-off during the next following month, and that the excessive precipitation is not reflected to any marked extent in the run-off for the same month in which such precipitation occurs.

### RUN-OFF DUE TO STORM PRECIPITATION.

Only casual examination of the data is required to make it apparent that storm precipitation during summer months often has marked effect on run-off in the Red River watershed. The effect is relatively greater and is more apparent on small watersheds of tributary streams than on large areas, because the most intense storm precipitation occurs on comparatively small areas. In figure 19 the precipitation during four summer storm periods, each on a different watershed, is indicated in comparison with run-off which followed the storms.

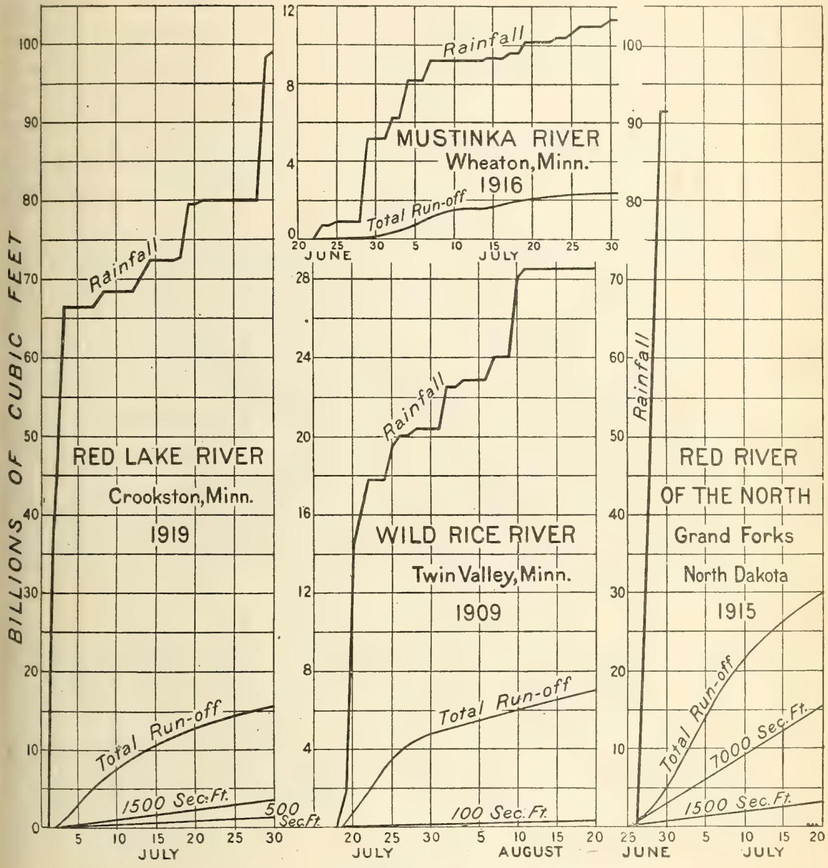

FIG. 19.—Accumulated storm rainfall and run-off.

On watersheds of 10,000 square miles or less, storm precipitation sometimes causes maximum run-off; but on the larger watersheds, such as that above Grand Forks, spring run-off due to melting snow is greater. Accordingly, figure 19 as well as other data on storm precipitation and summer run-off have been used largely in estimating probable maximum run-off for the smaller watersheds (see Table 5).

While figure 19 does not alone form sufficient basis for estimating maximum future run-off, yet the relations existing between volumes and intensities of precipitation and run-off, time periods, and areas are of importance in estimating future run-off which may result from summer storms.

### ESTIMATES OF PROBABLE RUN-OFF.

In Table 5 are shown the estimated rates of run-off for various subdivisions of the Red River watershed. The basis for these estimates is all available run-off records for annual, monthly, and daily periods, and for flood periods during spring and summer seasons, as well as data on precipitation and the results of a study of the various other conditions that affect run-off. As may be noted from Table 5, the rates of run-off shown are not expected to occur in such relation with respect to time that the excessive flow from all subdivisions will concentrate in the outlets.

Frequently, in connection with engineering reports on undertakings similar to the Red River project, certain formulæ or equations are developed or equations previously evolved are adopted for use in estimating run-off. In the present instance, however, each watershed is a problem of itself and any attempt to calculate run-off for the larger watersheds (say those of more than 200 square miles) by formulæ is likely to give results which would be quite unreliable owing to the wide variation of the influencing conditions and to the difficulty of assigning definite values to them. Accordingly no formula, equation, or curve has been developed and none is to be recommended.

### RUN-OFF FROM SMALL WATERSHEDS.

For small watersheds, containing less than about 200 square miles, the size of watershed drained is usually the dominating feature in determining the rate of run-off. For such areas a run-off formula in which the area of watershed is the principal factor may give satisfactory results if care and judgment are used in applying the formula.

TABLE 12.—*Estimated run-off, per square mile, from small watersheds.*

| Area (square miles). | Minnesota.[1] | North Dakota.[2] | Area (square miles). | Minnesota.[1] | North Dakota[2] |
|---|---|---|---|---|---|
| | *Cu. ft. per sec.* | *Cu. ft. per sec.* | | *Cu. ft. per sec.* | *Cu. ft. per sec.* |
| 1 | 12.0 | ........ | 25 | 8.7 | 6.7 |
| 2 | 11.2 | ........ | 30 | 8.5 | 6.6 |
| 3 | 10.7 | ........ | 40 | 8.3 | 6.4 |
| 4 | 10.4 | 13.4 | 50 | 8.1 | 6.2 |
| 6 | 10.0 | 11.8 | 75 | 7.8 | 5.9 |
| 8 | 9.7 | 11.2 | 100 | 7.7 | 5.8 |
| 10 | 9.5 | 10.0 | 150 | 7.3 | 5.3 |
| 15 | 9.1 | 8.4 | 200 | 7.0 | 5.1 |
| 20 | 8.9 | 7.7 | | | |

[1] By J. T. Fanning, 1886.

[2] By J. T. Stewart, 1907.

In preparing reports upon drainage projects in the Red River Valley, J. T. Fanning[7] (in Minnesota), and John T. Stewart[8] (in North Dakota), estimated run-off by a method in which the size of watershed is the principal variable considered. Their conclusions, as recorded for areas up to 200 square miles, are shown in Table 12.

### CONCLUSIONS REGARDING RUN-OFF.

Relative to seasonal variations of run-off, the study made by the Bureau of Public Roads indicated two important conclusions as follows:

1. No combination of storm and monthly precipitation is likely to occur from May to October which will cause the Red River to overflow below Wahpeton.
2. No storm precipitation will cause excessive run-off and floods in any portion of the watershed from November to March, when the prevailing temperature is low.

These two negative conclusions may be stated positively thus: Excessive precipitation may cause floods on any of the streams from May to October except along the channel of the Red River below Wahpeton. Rapidly melting snow, or a combination of precipitation and melting snow, may cause floods along any of the streams in the Red River watershed during March or April.

There is nothing to indicate that conditions as to rate or volume of run-off are undergoing any permanent change in the Red River Valley. Rather it seems probable that the future run-off during any long-term period will be subjected to seasonal and periodical fluctuations as great as any that have occurred in the past.

## THE FLOOD SITUATION.

Serious floods caused by rapid melting of snow and rain occur in early spring at intervals of from 1 to 15 years along the Red River below Wahpeton, N. Dak. These floods affect land and property in North Dakota and Minnesota, and in Manitoba, Canada.

During the period May to October local floods are caused by local storms which may cause very heavy rainfall over areas of 6,000 square miles or less.

### SPRING FLOODS.

Just after the annual spring thaw the run-off is sometimes sufficient to overflow the outside high banks of the channel. At such times extensive areas of land are flooded. As the land along the stream is flat and nearly level the flood water has very little current. Also, owing to the wide extent of the flat, level topography the flood depth is not great even when very large quantities of water overflow. These floods cause no damage to the land itself and a few generations ago, before agricultural development had begun in the valley, the floods were of no consequence. At present an extreme flood such as that of 1897 (see Pl. III, fig. 1), would damage much property, interfere with transportation, destroy live stock, and might cause loss of human life. Thus without increase in height or frequency of floods the possibilities of serious damage increases as the country develops and as population increases. A flood late in March may delay the preparation of the land and seeding long enough to greatly reduce yields, particularly of wheat, or may make it impossible to sow the lower portions of the fields at anything like the proper date. These spring floods are also important carriers of rank growing weeds of the river valleys.

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[7] Report of Commissioners, "Red River Valley Drainage," Crookston, Minn., 1886 (out of print).

[8] Bulletin 189, Office of Experiment Stations, U. S. Department of Agriculture, May, 1907 (out of print).

A feature of the Red River which has an important bearing on spring floods is its northward flow through a region of low winter temperatures and heavy ice. Spring thaws begin in the upper portions of the watershed and move gradually downstream, causing run-off from large areas to reach lower portions of the river when the winter ice is breaking up and beginning to move along the lower channel. The ice lodges against trees and other obstructions which partially fill the high-water channel of the stream. (See Plate III, figs. 2 and 3.) This retards the current and reduces materially the discharge capacity of the stream. Chandler[9] states, relative to retardation of flow by ice, that it has been found by measurements that during early spring floods "on some days * * * the water has been 2, 3, and even 6 and 7 feet higher than would have been necessary to discharge the same number of gallons per day later in the season when there is no ice retardation * * *."

### SUMMER FLOODS.

Throughout its entire length below Wahpeton the capacity of the Red River channel is sufficient to carry the average summer run-off of the watershed. Below the mouth of the Sheyenne River the capacity is greater than is necessary for average flow and is sufficient to carry the most extreme summer run-off likely to be caused by storm precipitation. Above the mouth of the Sheyenne River maximum summer run-off slightly exceeds the capacity of the waterway usually considered as being the stream channel but it does not overflow the outside high banks of the actual high-water channel of the river. At and above Fargo some flooding occurs within the high banks of the channel during summer months, seriously affecting highway traffic, city water, sewer facilities, and property on low

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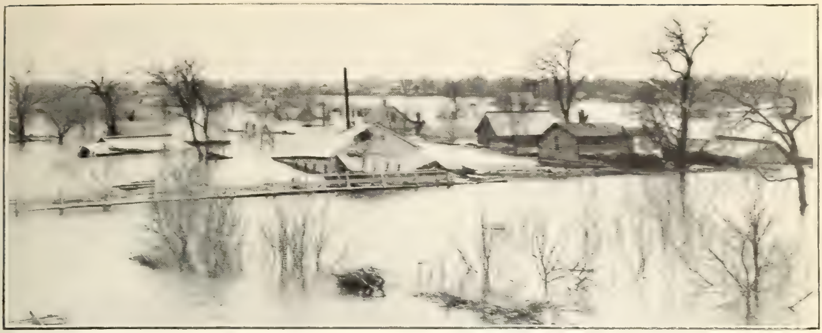
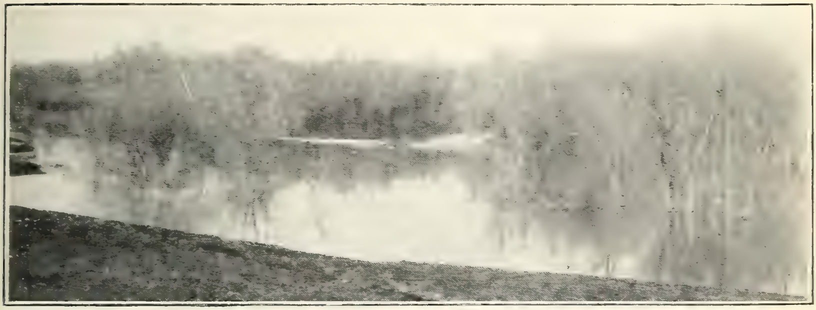
[9] "The Floods of the Red River Valley." Elwyn F. Chandler. The Quarterly Journal of the University of North Dakota, Vol. VIII, No. 3, April, 1918.



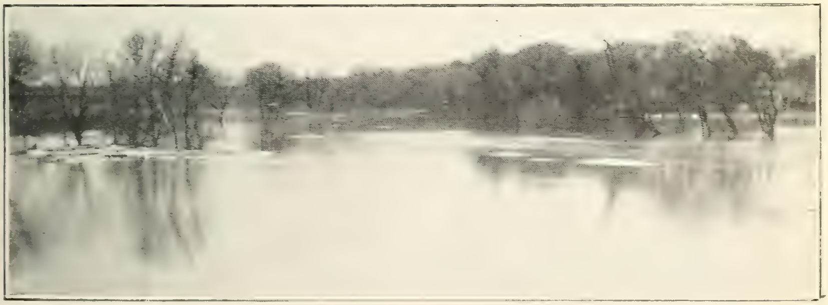
B. P. R.-D-4134

FIG. 1.—LOOKING ACROSS RED RIVER OF THE NORTH FROM MOORHEAD, MINN., DURING 1897 FLOOD.



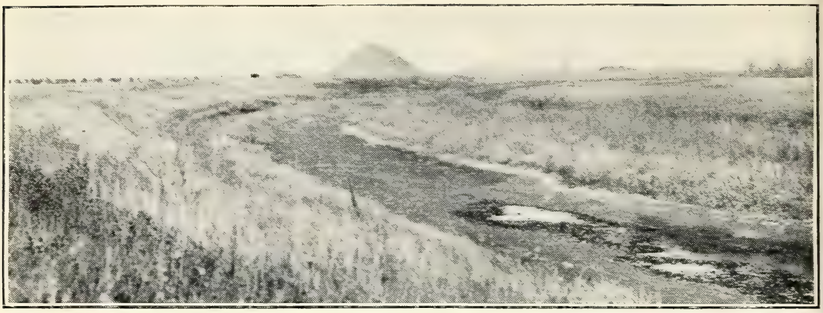
B. P. R.-D-3570

FIG. 2.—LOOKING ACROSS AND DOWN THE RED RIVER OF THE NORTH AT BEND EAST OF WILD RICE, N. DAK., DURING THE LOW FLOOD OF MARCH, 1920. NOTE HOW TREES IN CHANNEL OBSTRUCT THE FREE FLOW OF WATER.



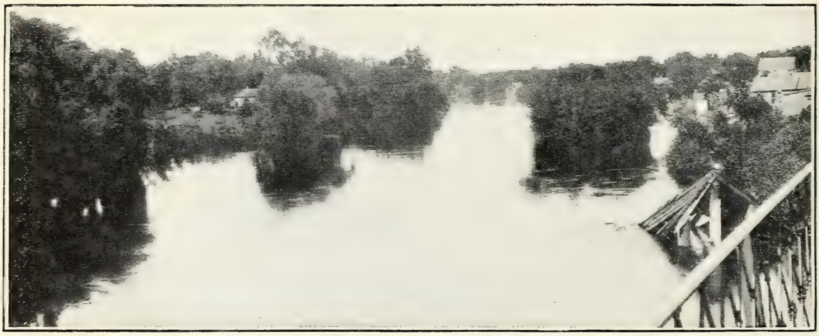
B. P. R.-D-3595

FIG. 3.—LOOKING DOWN THE RED RIVER OF THE NORTH FROM THE GREAT NORTHERN RAILWAY BRIDGE AT FARGO, N. DAK., MARCH, 1920. NOTE HOW TREES IN CHANNEL CATCH DRIFT AND DÉBRIS AND INTERFERE WITH THE FREE FLOW.



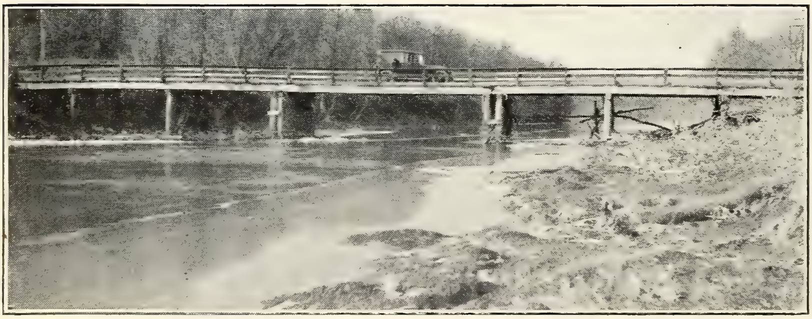
B. P.R.-D-1919

FIG. 1.—TYPICAL VIEW OF CHANNEL OF BOIS DE SIOUX RIVER SHOWING CONDITION OF CHANNEL BETWEEN WHITE ROCK, S. DAK., AND MOUTH OF RABBIT RIVER BELOW FAIRMOUNT, N. DAK., OCTOBER, 1918.



B. P. R.-D-4135

FIG. 2.—LOOKING UP RED RIVER OF THE NORTH FROM FRONT STREET BRIDGE, FARGO. N, DAK., JULY, 1916.



B. P. R.-D-3633

FIG. 3.—NORTH BROADWAY HIGHWAY BRIDGE NEAR FARGO, N. DAK. TYPICAL OF HIGHWAY BRIDGES BETWEEN FARGO AND GRAND FORKS. ON MARCH 28, 1920, THE WATER WAS 7 FEET ABOVE THE FLOOR OF THIS BRIDGE. THE BRIDGE RAILING FOLDS DOWN ON TOP OF THE BRIDGE. APRIL, 1920.

land along the stream; but no Red River overflow occurs below Wahpeton on land outside the real high-water channel of the stream during the crop-growing season. The land adjacent to the river that is overflowed is flooded by water from the tributaries of the Red, or by water which comes from rains.

### FLOOD RECORDS.

During the last 40 years, the period for which definite records are available, the Red River at Grand Forks has risen above flood stage (elevation 819.5, stage 40 feet, U. S. G. S. gauge) seven times, viz, 1882, 1883, 1893, 1897, 1904, 1916, and 1920, each time in the spring soon after the annual spring thaw. Only in one case did high stages occur in two consecutive years (1882 and 1883). The longest period between flood stages was 12 years (1904–1916). Elevations and dates of high and low river stages at three stations, Fargo and Grand Forks, N. Dak., and Emerson, Manitoba, are shown in Table 13.

TABLE 13.—*Elevations and dates of flood crests and low-water stages.*

| Year. | Fargo, N. Dak. (flood stage 887.5). | | Difference (Distance 155 miles). | | Grand Forks, N. Dak. (flood stage 819.5). | | Difference (Distance 143 miles). | | Emerson, Manitoba[1] (flood stage 779.5). | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Date. | Elevation. | Days. | Feet. | Date. | Elevation. | Days. | Feet. | Date. | Elevation. |
| 1882 | Apr. 11 | 899.2 | 10 | 70.2 | Apr. 21 | 829.0 | ........ | 38.9 | ........ | 790.1 |
| 1883 | ........ | ........ | ........ | ........ | Apr. 28 | 820.1 | ........ | ........ | ........ | ........ |
| 1893 | ........ | ........ | ........ | ........ | Apr. 24 | 825.0 | ........ | 35.2 | ........ | 789.8 |
| 1897 | Apr. 7 | 901.5 | 3 | 71.8 | Apr. 10 | 829.7 | 12 | 39.1 | Apr. 22 | 790.6 |
| 1902 | Mar. 29 | 871.8 | 2 | 66.4 | Mar. 31 | 805.4 | 4 | 26.9 | Apr. 4 | [2] 778.5 |
| | Sept. 20 | 869.2 | 4 | 88.4 | Sept. 24 | 780.8 | 6 | 30.8 | Sept. 30 | [2] 750.0 |
| 1903 | Apr. 6 | 875.7 | 5 | 68.2 | Apr. 11 | 807.5 | ........ | ........ | ........ | ........ |
| | Oct. 12 | 870.3 | 2 | 80.2 | Oct. 14 | 790.1 | ........ | ........ | ........ | ........ |
| 1904 | Apr. 20 | 883.1 | 7 | 63.0 | Apr. 27 | 820.1 | ........ | 34.1 | (3) | 786.0 |
| | June 28 | 876.6 | 3 | 82.9 | July 1 | 793.7 | ........ | ........ | ........ | ........ |
| 1905 | Mar. 31 | 871.3 | 6 | 74.3 | Apr. 6 | 797.0 | ........ | ........ | ........ | ........ |
| | May 17 | 880.2 | ........ | 74.7 | May 16 | 805.5 | ........ | ........ | ........ | ........ |
| 1906 | Apr. 9 | 877.3 | 9 | 61.8 | Apr. 18 | 815.5 | ........ | ........ | ........ | ........ |
| | July 5 | 874.5 | 1 | 80.3 | July 6 | 794.2 | ........ | ........ | ........ | ........ |
| 1907 | Mar. 30 | 891.6 | 8 | 72.3 | Apr. 7 | 819.3 | ........ | ........ | ........ | ........ |
| | June 17 | 881.1 | 1 | 81.2 | June 18 | 799.9 | ........ | ........ | ........ | ........ |
| 1908 | Apr. 5 | 875.7 | 6 | 63.4 | Apr. 11 | 812.3 | ........ | ........ | ........ | ........ |
| | June 13 | 876.5 | ........ | 79.1 | June 13 | 797.4 | ........ | ........ | ........ | ........ |
| 1909 | Mar. 30 | 874.8 | 9 | 78.8 | Apr. 8 | 796.0 | ........ | ........ | ........ | ........ |
| | Aug. 12 | 871.4 | 5 | 74.6 | Aug. 17 | 796.8 | ........ | ........ | ........ | ........ |
| 1910 | Mar. 19 | 884.9 | 3 | 74.7 | Mar. 22 | 810.2 | ........ | ........ | ........ | ........ |
| | Oct. 29 | 867.4 | 7 | 84.9 | Nov. 5 | 782.5 | ........ | ........ | ........ | ........ |
| 1911 | Apr. 11 | 870.5 | 4 | 81.8 | Apr. 15 | 788.7 | ........ | ........ | ........ | ........ |
| 1912 | Apr. 8 | 872.2 | 1 | 80.0 | Apr. 9 | 792.2 | ........ | ........ | ........ | ........ |
| | May 14 | 872.4 | ........ | 84.3 | May 14 | 788.1 | 2 | 35.6 | May 16 | 752.5 |
| 1913 | Apr. 15 | 871.8 | ........ | 65.7 | Apr. 8 | 806.1 | 3 | 30.6 | Apr. 11 | 775.5 |
| | July 8 | 873.7 | 4 | 87.1 | July 12 | 786.6 | 4 | 36.2 | July 16 | 750.4 |
| 1914 | ........ | ........ | ........ | ........ | Apr. 9 | 791.9 | 8 | 33.6 | Apr. 17 | 758.3 |
| | May 2 | 875.5 | 3 | 83.8 | May 5 | 791.7 | ........ | ........ | ........ | ........ |
| | June 12 | 877.7 | 5 | 80.0 | June 17 | 797.7 | 2 | 38.4 | June 19 | 759.3 |
| 1915 | Apr. 9 | 887.2 | 2 | 88.6 | Apr. 11 | 798.6 | 2 | 38.0 | Apr. 13 | 760.6 |
| | July 2 | 888.2 | 1 | 77.9 | July 3 | 810.3 | 6 | 40.3 | July 9 | 770.0 |
| 1916 | Apr. 6 | 892.1 | 11 | 71.6 | Apr. 17 | 820.5 | 7 | 33.8 | Apr. 24 | 786.7 |
| | July 12 | 889.4 | 2 | 85.8 | July 14 | 803.6 | 5 | 38.8 | July 19 | 764.8 |
| 1917 | Apr. 3 | 886.2 | 3 | 74.3 | Apr. 6 | 811.9 | 5 | 35.6 | Apr. 11 | 776.3 |
| | Aug. 28 | 869.8 | 5 | 86.8 | Sept. 2 | 783.0 | 3 | 35.6 | Sept. 5 | 747.4 |
| 1918 | Mar. 30 | 871.8 | ........ | 81.0 | Mar. 28 | 790.8 | 3 | 31.7 | Mar. 31 | 759.1 |
| | Sept. 20 | 869.8 | ........ | 85.9 | Sept. 20 | 783.9 | 1 | 36.4 | Sept. 21 | 747.5 |
| 1919 | Mar. 24 | 872.8 | 10 | 76.0 | Apr. 3 | 796.8 | 6 | 28.5 | Apr. 9 | 768.3 |
| | July 5 | 870.3 | 4 | 68.5 | July 9 | 801.8 | 3 | 36.6 | July 12 | 765.2 |
| | Sept. 19 | 868.9 | ........ | 83.7 | Sept. 19 | 785.2 | ........ | 36.0 | Sept. 19 | 749.2 |
| 1920 | Mar. 27 | 885.5 | 2 | 65.1 | Mar. 29 | 820.4 | 10 | 40.8 | Apr. 8 | 779.6 |

[1] Emerson gauge established May, 1912.

[2] Datum uncertain.

[3] Pembina.

Only two of the spring rises have resulted in serious floods throughout the entire valley; these occurred in April, 1882, and April, 1897, the latter being the maximum for which reliable records are available. The floods of 1893 and 1904 were more serious between Grand Forks and the international boundary than in other parts of the valley. The 1916 flood was most serious in the vicinity of Fargo and in upper portions of the valley, but it was of slight consequence at and below Grand Forks.

With regard to floods along the part of the river within the United States, records prior to 1880 are vague because no systematic method for recording gauge heights had been in use before that time. Information as to floods prior to 1860 is merely legendary. According to legend a flood occurred in 1852 which was from 1 to 10 feet higher than the 1882 flood at and below Grand Forks. Reliable records of floods since 1826 at Winnipeg, Manitoba, are available. The extreme floods there occur in May, nearly a month later than at Grand Forks, and are caused by fortuitous occurrence of high stages in the Red River and the Assiniboine River, which joins the Red within the city of Winnipeg. The maximum flood recorded at Winnipeg crested May 22, 1826, about 15 feet above the ordinary flood height in that locality. A flood 1½ feet lower crested May 22, 1852, and stages about 4 feet lower than that of 1826 are said to have occurred in 1776, 1790, and 1809. The highest flood since 1852 occurred in 1882 when the crest was 11 feet lower than in 1826. The crest of the flood of 1882 in the Red River passed Winnipeg several days before that of the Assiniboine reached the junction of the streams; thus a greater flood was averted. Considering these records for the lower river it appears probable that in 1852 a flood higher by one or more feet than that of 1882 occurred along the river at and below Grand Forks.

The records indicate that a serious flood may occur in any year; that the probable frequency is once in 15 years; and that the probable longest period without a flood is 30 years.

### THE LAKE TRAVERSE—BOIS DE SIOUX—RED RIVER CHANNEL.

The Red River of the North is formed at Breckenridge, Minn., by the junction of the Bois de Sioux and Otter Tail Rivers, and follows a sinuous course to the north for about 394 miles to the international boundary; thence it continues to Lake Winnipeg. The Bois de Sioux River rises in Lake Traverse, the total length of the combined watercourse from the upper end of Lake Traverse to the Canadian line being 456 miles, which is approximately twice the distance between the two points as measured in a straight line. (See fig. 1.) The stream flows northward through the center of the bed of the ancient glacial Lake Agassiz, the land on both sides being very flat for some distance back from the banks. The fall along its course is for the most part slight and somewhat variable. Along the Bois de Sioux the fall is about 0.3 foot per mile; from Breckenridge to Fargo, about 1 foot per mile; and from Fargo to the Canadian line from 0.6 to 0.3 foot per mile. (See fig. 2.)

The channel of the upper Bois de Sioux is small and poorly defined (see fig. 4 and Plate IV, fig. 1), but in the vicinity of Breckenridge the banks are between 20 and 25 feet high, and from 100 to 200 feet apart. At this point there is a further increase in size due to the entrance of the Otter Tail, and from Breckenridge on for the greater part of its length the stream has an inner or low-water channel with banks of varying height, with one or more terraces on each side which bring the outer banks up to or slightly above the level of the adjacent land. The outer banks, in places on the lower part of the river, are from 1,000 to 1,200 feet apart.

The course is extremely crooked for most of its length, with many loops, bends, and side channels. The channel often doubles back upon its course and flows a considerable distance without gain in the general direction of flow. Over the greater part of its length the channel—especially the outer flood channel—is badly obstructed by trees and brush (see Pl. IV, fig. 2) and many buildings, fences, and other structures are situated within the outside banks. Many of the county wagon bridges have been built on the inner banks, spanning only the low-water channel (see Pl. IV, fig. 3); at flood stages these are either washed out or completely covered, thus forming additional obstruction to flow.

Owing to the slight fall in the stream bed and the fact that the slope decreases downstream as more water is added, the velocities of flow are small and channel erosion is comparatively slight. The stream under these conditions has not a channel of sufficient capacity at all points to carry the volumes of water present at high stages, and the situation is rendered the more acute by the obstructed state of the channel. As a result, heavy run-off from the watershed causes the stream entirely to fill the channel and spread widely over the contiguous country.

The upper part of the Bois de Sioux has practically no channel (Pl. IV, fig. 1) and at times of high water the adjacent land to the west becomes a part of Lake Traverse. The land to the east rises sharply a short distance from the stream. Farther down, the channel gradually develops until at a point about 10 miles upstream from Breckenridge it attains a capacity of 2,000 second-feet (see fig. 2 and fig. 4). At Breckenridge there is a sharp increase in slope and size of channel which gives a capacity of about 4,000 second-feet within the inner banks and about 8,500 second-feet for the entire channel. From Breckenridge to the international boundary there is a continuous increase in size of channel of the Red River and a decrease in the general slope of the channel, broken by short stretches of greater fall (see fig. 2).

When the water in the river reaches a stage of 23 feet on the gauge maintained by the United States Weather Bureau at Moorhead, Minn., the water starts to overflow the inner banks and reaches some of the lower lying road grades, buildings, and bridges—the channel between the mouth of the Dakota Wild Rice River and the mouth of the Sheyenne River will easily carry 6,000 second-feet. A rise above 23 feet causes the overflow of low areas within loops of the river and parts of the city of Fargo which lie but slightly above the banks of the lower-water channel. Even at stages as high as 35 feet at Fargo no extensive areas of land are flooded. Below the mouth of the Sheyenne River the channel of the Red River will carry 12,000 second-feet, and from the mouth of the Buffalo to Grand Forks 15,000 second-feet can be passed without overflow. Below the mouth of the Red Lake River at Grand Forks the channel is considerably larger than above, and in the stretch between that point and the international boundary, along which the slope constantly diminishes, are found the sections of maximum area (see figs. 2 and 4). This part of the channel will carry a volume of 25,000 second-feet without topping the outer bank.

It should not be presumed that the river when flowing at these maximum rates will entirely fill the channel for its whole length, or that greater volumes can not be carried at some points without overflow. The figures given refer to the approximate maximum volumes that can be passed through the various sections of the channel without overflow at any point along the river. Greater volumes can be carried at certain points, but even though the river remains within the banks at these points it will overflow either above or below. When flowing bank-full, on the other hand, the smaller sections pass more water than their size and the slope of the stream as a whole would indicate. This is due to the heading up of the water above the sections of small area, and the ability of the larger sections below to carry the same volume at lower stages, which gives an increased water-surface slope through the restricted portions. The capacity as calculated by Kutter's formula agrees very closely with actual discharge as indicated by stream-gauging records.

### TRIBUTARY STREAMS.

In some respects the tributary streams are much like the Red River, the fall being slight in the lower parts of the channels. However, in their upper reaches the fall in most cases is much greater than in the Red. These streams rise outside the old lake boundary and flow from the east and west through the old beaches across the flat lake bed and into the main river. In many cases they parallel the river for some distance before finding outlet. They have sinuous courses and the channels are more or less obstructed by vegetation. Many of them originally spread out as marshes over the flats along the Red River and had no definite channels for some distance. Some of these streams have been improved through the flat areas by artificial channels which carry the water coming down from the higher parts of the basin and also provide outlet for the drainage of the marsh lands. The flow in the lower parts of most of these tributaries is sluggish, and many are subject to overflows during heavy run-off. Overflow near the mouth is caused in some cases by backwater from the Red River.

## EFFICIENCY OF THE NATURAL DRAINAGE SYSTEM.

The general condition of the natural streams of the watershed results, during periods of heavy run-off, in constantly augmented bodies of water coming down badly obstructed channels of small and constantly diminishing slope, piling up as they progress, overflowing stream banks, and finally all uniting in a common channel characterized by the same conditions of slight fall, obstruction to flow, and diminishing slope; all this resulting in the overflow of large areas of flat land along the main stream. A study of the various streams of the basin shows that, with the exception of those with relatively small contributing areas, the channels are or can be made sufficient to carry the run-off during the summer months without overflow. In cases of intense local storms over limited areas, serious damage has at times resulted from flooding during the summer, but where the drainage area involved is greater than about 6,000 square miles the extent of heavy precipitation and the concentration of the run-off is not great enough to cause damaging overflow. It is the spring run-off, resulting from melting snow and ice and the general spring rains, that causes the floods which cover a large portion of the valley.

## ARTIFICIAL CHANNELS.

Artificial drainage channels serve the double purpose of facilitating the movement of the flood waters to the natural channels and of providing outlet where natural drainage is lacking or inadequate. In the former capacity they provide a means for the rapid escape of the excess surface water during periods of snow melting and heavy precipitation, removing it quickly to the natural channels. In swamp regions they remove the permanent excess of water, making possible the agricultural development of the land. They are, in short, an elaboration of the natural drainage system of the watershed.

The Red River watershed includes large areas of land that originally were sloughs, marshes, and swamps. These are of two classes with respect to location and origin of swampy condition; namely, those lying near the Red River in the bed of the glacial Lake Agassiz, and those outside the old beaches and situated at a considerably higher elevation. The former owe their existence as marsh land to the spreading of the larger streams as they came from the higher ground into the flat lake bed, and to small creeks, blind coulees, and general surface flow on to the almost level land bordering the river. These swamp areas lie on both sides of the Red River for the greater part of its length and generally are free from timber. The second-named type of swamp results from insufficient outlet due to flatness and to natural barriers to stream flow in the form of ridges. Most swamps of this class lie in the eastern part of the watershed. Some the low pockets entirely surrounded by higher land, but for the most part they are swamps of comparatively wide extent and are permanently saturated. Direct precipitation, surface flow, and small streams constitute the source of their water. Lying as they do in the upper part of the watershed, no large streams traverse them as in the case of those in the lower levels. In fact, most of the larger streams which contribute to the swampy conditions below have their sources in these upper areas. These swamps, for the most part, originally were timbered, although in places there were considerable areas of open country and more has been cleared as drainage activities have progressed.

## DRAINAGE DITCHES.

In studying the artificial drainage of the watershed the flat areas which form the old lake bed were considered separately from the upland areas. The lands included in the former class are those lying on both sides of the river inside the 1,050-foot contour (see fig. 1) from Lake Traverse to the north line of Richland and Wilkin Counties; inside the 1,000-foot contour from there to an east-west line through Fargo; inside the 950-foot contour from Fargo to an east-west line through Grand Forks; and inside the 900-foot contour from there to the Canadian boundary. The drains which serve these lowlands have but little fall and lie only slightly higher than the Bois de Sioux and Red Rivers which they enter either directly or through short reaches of natural streams. Consequently, they depend to a large extent for efficiency upon the conditions of river flow and are intimately connected with any project concerning the river. The upland systems, with greater fall and free-flowing outlets, are not directly concerned with the conditions below.

The wet lands along the main watercourse have been improved by enlarging and extending the channels of the larger streams, and by systems of open ditches. The most extensive work of this nature has been done on the Minnesota side, where the greater part of the land along the river is now under cultivation although much improvement to drainage is still possible. Considerable drainage work has been carried out on the Dakota side also, but there still remain large areas of marsh land which are not used at all, or at best are used only as wild hay land or pasture. In Table 14 are shown, for each county involved, the areas of land lying within the limiting contours of the lowland country, the amount of low land within one-half mile of artificial drains, and the percentage of land thus served. This table shows clearly how much greater has been the progress of artificial drainage development on the east side of the river than on the west. Many of the marshes in the flats along the river are brackish, as is also the ground water under them.

TABLE 14.—*Artificial drainage of Red River lowlands.*

| County. | Total area of lowland. | Area within one-half mile of drains. | | County. | Total area of lowland. | Area within one-half mile of drains. | |
|---|---|---|---|---|---|---|---|
| Minnesota: | *Sq. mi.* | *Sq. mi.* | *Per cent.* | North Dakota: | *Sq. mi.* | *Sq. mi.* | *Per cent.* |
| Traverse | 307 | 184 | 60.0 | Richland | 835 | 55 | 6.6 |
| Grant | 190 | 45 | 23.7 | Cass | 937 | 176 | 18.8 |
| Wilkin | 588 | 218 | 37.1 | Traill | 492 | 52 | 10.6 |
| Clay | 617 | 230 | 37.3 | Grand Forks | 639 | 22 | 3.4 |
| Norman | 509 | 224 | 44.0 | Walsh | 501 | 27 | 5.4 |
| Polk | 1,061 | 604 | 56.8 | Pembina | 730 | 143 | 19.6 |
| Marshall | 543 | 206 | 37.9 | | | | |
| Kittson | 576 | 103 | 17.9 | Total | 4,134 | 475 | 11.5 |
| | | | | South Dakota: | | | |
| Total | 4,391 | 1,814 | 41.3 | Roberts | 43 | 0 | 0 |

The workings of the drainage laws, through the arbitrary fixing of the extent, location, and channel sizes of ditch systems, have often hindered engineers in their efforts to design adequate means for relief. At times of flood in the Red River and in the lower parts of its tributaries, back water from these streams prevents the normal flow of water in the outlet ditches.

Very extensive drainage systems have been constructed in the higher parts of the watershed on the Minnesota side of the river. They furnish outlet through or around ridges, give adequate fall through flat areas, and provide means for lowering the water table in higher swamp regions. In many cases the immediate local drainage of the territory affected has been given attention; while in others only the general outlet channels have been provided, leaving the smaller local drains to be taken up as the development of the locality warrants. Very little drainage has been required in the uplands on the west side of the river north of an east-west line through Fargo.

The results of artificial drainage in the upper parts of the watershed have been generally satisfactory, although in some cases the work has not been comprehensive enough to provide for extensions that have or may become desirable; moreover, proper attention to the outlet facilities has been neglected in some, and in others the design of the system has been faulty. Many of the early ditches were shallow, and too small to afford good drainage. The ditches that are now being constructed are generally deeper and larger, and are therefore much more efficient as drains. The snow and ice in the spring fill many of the drains, but there seems to be no way to overcome this difficulty.

Damaging floods have occurred in Thief and Roseau River basins at times of extraordinary storms such as that of July, 1919 (see fig. 12 and Table 9). A part of this area is extensively ditched, many of the land sections having ditches on two or three sides. Nevertheless at the time mentioned the ditches and streams overflowed, the water completely submerging large areas and doing great damage. The trouble seems to have been due, mainly, to the inability of the two rivers in their present condition to carry off the water brought to them through the artificial channels, and to some extent to the over-taxing of these artificial channels by the run-off from too large areas. Under normal conditions most of the land affected is free from damaging water.

The development of graded highway construction throughout the watershed has grown to be a somewhat important factor in the removal of run-off. As it has progressed, more and more attention has been given the proper drainage of road grades until at present practically no new construction is undertaken without provision for the removal of water which might prove injurious to the roads. The network of road ditches which is rapidly spreading over the entire watershed has a marked and increasing effect upon the rapidity with which the run-off from spring thaws and storms collects in the streams and drainage ditches and is a factor not to be neglected when considering the rates of run-off over the drainage basin. On the other hand, road embankments in some localities have interfered with drainage outlets.

### TILE DRAINAGE.

Tile drainage has barely passed the experimental stage in the Red River Valley, but the practicability of this method of local drainage for the farm lands of this valley has been fully demonstrated by tests that have been carried on continuously since 1907 at the Minnesota State Experiment Farm at Crookston and by several private undertakings. The soil in which these tests have been made is typical of that occurring generally over the flat areas along the river and the results obtained are indicative of what may be accomplished throughout the low-lying lands. The private tile systems that have been installed have operated with varying degrees of success. It is doubtful whether the design has been proper in all cases. The upland soils are of a lighter, more porous character, and the question of successful tile drainage is one of proper design and construction rather than of practicability.

The very dense soil of the lowlands takes water slowly. During wet seasons the soil often remains completely saturated and even submerged for considerable periods. The light slope of the land retards the surface flow and crops frequently are damaged through the presence of this excess water. Tile drains, properly placed, provide direct channels to the outlet. They rapidly remove the free water from the soil, thus quickly renewing its capacity for absorption and in time increasing the porosity of the soil above the drains, thereby accelerating percolation and the removal of excess water. Surface evaporation is decreased during dry periods, especially on cultivated lands. The net result of tile drainage, therefore, is a reduction of the bad effects of excessive moisture during wet periods and of deficient moisture at times of drought. In the uplands are many areas too wet to be cultivated that can be made arable by tile drainage. As the development of farming progresses, more and more of this higher-lying land will be improved by this means.

## RECOMMENDED PLAN OF DRAINAGE.

The surveys and investigations revealed clearly that the securing of adequate drainage for the wet and overflowed lands in the valley of the Red River of the North requires that floods be either controlled or reduced in stage as much as possible and that adequate drainage ditches be provided to remove excess water rapidly from those lands which have insufficient natural drainage.

It was found that in the watershed of Lake Traverse and the Bois de Sioux River (see fig. 1), the conditions affecting drainage and flood control were such that the improvements in this section of the valley must be constructed as one project. However, in preparing the plans the effect of the recommended improvements upon the flood situation in the lower valley was given careful consideration. The work in the valley separates into three projects, which can be carried out separately or as one large project. These are the Lake Traverse-Bois de Sioux, the Red Lake-Red Lake River, and the Red River of the North projects.

### LAKE TRAVERSE—BOIS DE SIOUX PROJECT.

#### SUMMARY OF RECOMMENDED WORKS.

The improvements recommended in the Lake Traverse-Bois de Sioux watershed are, briefly, the following:

1. A detention reservoir to be formed in Lake Traverse by the construction of an earth dam provided with spillway and outlet con-

trol and extending across the watercourse and the adjacent lowland near White Rock, S. Dak., and also an earth levee at the south end of the lake, near Browns Valley, Minn.

2. A new channel for the Bois de Sioux from the dam in Lake Traverse to a point near Wahpeton, N. Dak., where the natural channel will carry the water without flooding.

3. A system of ditches to provide for the drainage in the areas to be reclaimed by the project.

In addition it will be necessary to replace some of the present bridges with larger ones and to construct new ones at points where the operations would otherwise interfere with transportation.

These improvements are designed to relieve flood conditions, make possible the reclamation of the wet lands along the Bois de Sioux, and provide outlets for the drainage necessary to the development of this area.

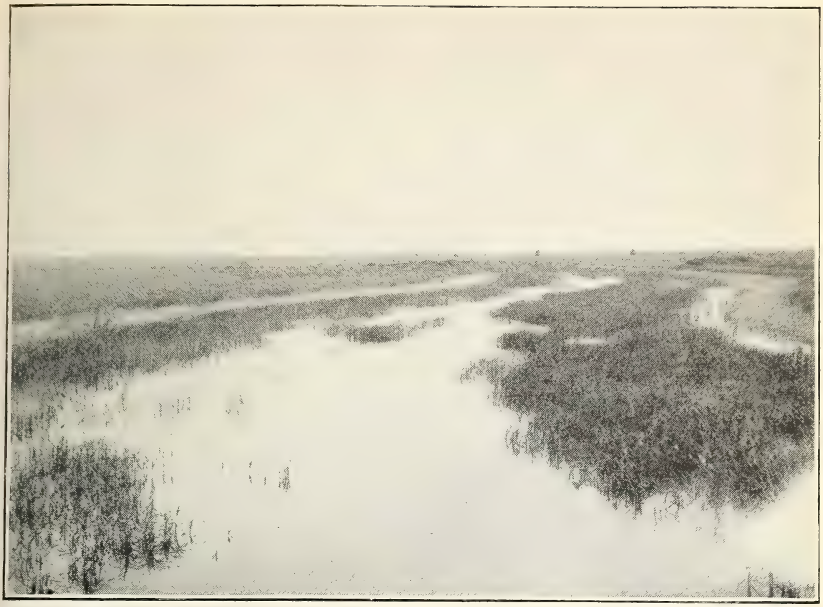
### DESCRIPTION OF WATERSHED.

Lake Traverse and the Bois de Sioux River, with their tributary watershed, include the south end of the bed of the glacial Lake Agassiz and the land adjacent to its shores. The nature of the topography and soil is a result of glacial action and subsequent natural processes as previously discussed. The soil is alluvium, composed of clay mixed with varying quantities of fine sand and organic matter, with occasional bowlders occurring in the vicinity of White Rock. It is fertile, and when drained and cultivated produces good crops of wheat and other small grains, potatoes, grasses, and vegetables and fruits adapted to the climate.

That part of the watershed lying in North and South Dakota, together with a strip approximately 30 miles wide just east of the Bois de Sioux and Lake Traverse in Minnesota, is prairie land. The only timber occurs in strips, varying in width from 100 feet to one-half mile, along the principal streams. The land is flat and rises in a gentle slope on both sides. Practically all the prarie land has been cultivated.

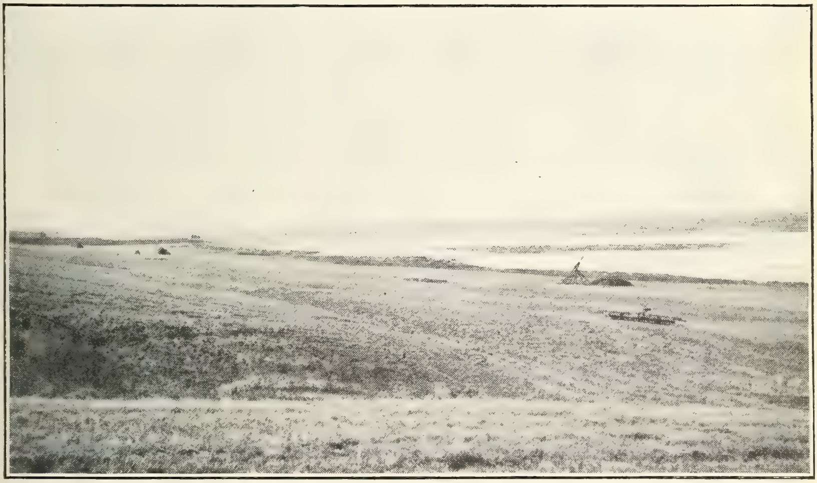
The eastern portion of the watershed, in Minnesota, was originally covered by forests. The topography is quite rough and there are many depressions, in some of which are found lakes while others are simply marshes. Over much of the area the timber has been cut and the lands cleared, until at present probably less than 10 per cent of this area is forested. The total area of the watershed above the junction of the Bois de Sioux with the Otter Tail, at Breckenridge, Minn., is 1,875 square miles.

Owing to the flatness of the land surface and to the limited quantities of water which the drainage channels have carried, the latter are poorly developed and are not large enough to carry off the excess of



B. P. R.-D-3097

FIG. 1.—CHANNEL OF BOIS DE SIOUX RIVER EAST OF FAIRMOUNT, N. DAK. WATER 4 FEET DEEP, 60 TO 120 FEET WIDE, DISCHARGE ONLY 42 CUBIC FEET PER SECOND. JULY, 1919.



B. P. R.-D-3632

FIG. 2.—LOOKING SOUTH ALONG EAST SHORE OF LAKE TRAVERSE. SITE OF PROPOSED DAM SOUTH OF WHITE ROCK, S. DAK., APRIL, 1920.

precipitation without overflow. Three conditions make additional surface drainage necessary: (1) Flat or nearly level land surface without natural drainage channels; (2) depressions in which water collects and stands because of lack of outlet; and (3) natural channels too small to serve properly the areas they drain. Heavy soils or other conditions make underdrainage necessary in many localities. The north shore line of Lake Traverse is not well defined (see fig. 3, sheets 2 and 3), and during high stages the lake overflows the land several miles to the north. Much of this land has been or is now cultivated and the remainder is used to some extent as hay land.

The present channel of the Bois de Sioux is entirely inadequate to carry the water that comes to it from Lake Traverse (see Pl. V, fig. 1). The cross sections (fig. 4) show that near Lake Traverse the stream has practically no channel. As one goes downstream the size of the channel gradually increases until at Breckenridge it is large and well defined. The Mustinka River, which drains 852 square miles, rises in the hills near Fergus Falls and flows south about 25 miles and then west and southwest to Lake Traverse. Practically all of the watershed of the Mustinka in Traverse County (see fig. 1) has been drained by ditches spaced approximately 1 mile apart. In that county the channel of the Mustinka has been dredged and straightened for a considerable portion of its course. The Rabbit River drains approximately 300 square miles lying north and west of the Mustinka. It enters the Bois de Sioux about 10 miles south of Breckenridge (see fig. 3, sheets 3 and 4). As shown in fig. 1, a considerable portion of its watershed has been drained by open ditches spaced 1 mile apart. From a point about 4 miles south of White Rock, S. Dak., north to Fairmount, N. Dak., there is a strip of land along the Bois de Sioux which is frequently overflowed. From Fairmount north to Breckenridge the lands are occasionally overflowed. At times serious damage is caused by water from the Wild Rice River in North Dakota breaking out of its banks, flowing east, and flooding the land between its channel and the Bois de Sioux. Similar conditions exist on the Rabbit River and Otter Tail River, which flood land southeast of Breckenridge.

As the channel of the Bois de Sioux is too small to remove the water which comes to it when heavy rains occur, much land is flooded and the drainage of the higher-lying lands is obstructed. The flood water drains off slowly through the inadequate watercourse or remains on the land until evaporated. In years when heavy rains occur during the summer months, the crops are seriously damaged or completely destroyed. This damage becomes more serious if preceded by a wet spring. Floods are frequently caused by the melting of snow in the spring. These spring floods cause some damage by interfering with farming operations and prevent planting at the proper time.

The information collected shows very clearly that the highest floods are those caused by melting snow, combined in some instances with rains at a time of the year when the ground is more or less impervious to water. However, the floods that have caused the greatest loss to crops have been those caused by heavy rains over the watershed during the period from May to August. The natural drainage is not capable of removing the run-off from heavy storms, such as occurred in 1916, in time to prevent flooding and serious damage to crops. In many instances where an attempt has been made to relieve this condition by constructing ditches, it has not been possible to secure a satisfactory outlet or the drains have been dug too shallow and too small.

## THE PROBLEM.

In order to relieve the conditions just described, it is necessary either to provide channels of sufficient capacity to remove the run-off from storms and spring thaws without flooding or so to control this run-off that the drainage channels shall not be overtaxed. A combination of the two methods is recommended as most advantageous. A number of different plans for accomplishing these results were given careful study. No discussion will be given of the several plans considered but not adopted.

In reaching conclusions as to the conditions which must be met in planning the improvements extensive and detailed studies were made of all available precipitation and run-off records. These studies and the methods used in estimating requirements have been discussed, and only those phases that apply to this project in particular will be taken up here.

In planning for the drainage of this watershed provision has been made only for outlet drainage. Only those works have been included that will require joint action of the three States interested. Some suggestions are made as to lateral drainage, but it is believed that these local drains can be constructed most economically under the drainage laws of the State in which the drains are located.

## THE DETENTION RESERVOIR.

The reservoir, by means of which it is proposed to control the run-off from the Lake Traverse watershed, would include that part of the present bed of the lake between Browns Valley, Minn., and the north line of sections 24 and 33, T. 128 N. Along this line, which is about 4 miles south of White Rock, S. Dak. (see Pl. V, fig. 2), it is planned to build the earth dam extending to high ground on both sides. The proposed sluiceway for controlling the outflow is located at the intersection of the dam with the Boise de Sioux channel, and the spillway for protecting the dam from damage by overflow is placed at the extreme east end. Both of these structures are to be of reinforced concrete. For the location, elevation, and dimensions of the dam see figure 3, sheet 2, and figure 4. A levee at the south end of the lake, near Browns Valley, will be necessary to prevent overflow into Bigstone Lake. A channel extending about 2 miles back into the reservoir is planned to facilitate flow to the sluiceway. The embankment of the railroad spur from Browns Valley to the grain elevator at the south end of Lake Traverse must be raised to avoid interruption of traffic by water in the reservoir. (See fig. 3, sheet 1.) On account of the navigation on Lake Traverse it is not permissible to lower the water surface of the lake artificially below elevation 972, the present low-water stage. As the breaking of the reservoir when full would cause a great flood and much damage to property and crops, it has been made of such dimension as will give a large factor of safety, and it will store the run-off from a storm much larger than any on the Red River of which we have a record.

### RUN-OFF TO BE CONTROLLED.

Fairly complete precipitation records from about 1893 to date are available, as are also data (April, 1917, to date) from which the discharge of the Mustinka River into Lake Traverse can be computed, and for the discharge of the Bois de Sioux for 1919 and 1920. In addition there are some data relative to flood heights and a few measurements of run-off made in the watershed. Also, there is available considerable information in regard to run-off from other drainage areas in the watershed of the Red River. The records of discharge are shown in Table 3. In view of the paucity of actual flood discharge measurements it was necessary, in order to decide upon the probable run-off from the watershed under consideration, to establish some relation between precipitation and run-off.

In studying the available records of run-off, as shown in Table 3, it was found that by far the greatest run-off per square mile that has ever been recorded in any watershed tributary to the Red River occurred in the Wild Rice watershed in Minnesota as a result of the storm of July 21–23, 1909. (See Table 9.) Computations of monthly and annual run-off for the period July, 1909, to December, 1917, also show that the maximum monthly and half-yearly run-off measured during that period occurred on the Wild Rice River during 1909.

As the run-off from January to June, 1909, was not measured and a maximum year could not be estimated therefrom, the records from January to June, 1916 (showing maximum half-yearly run-off since 1909), and from July to December, 1909, were combined as though they had occurred in one year. The period January to June, 1916, was selected because the heaviest run-off for the first six months of a year was recorded during that year. The precipitation for these periods is shown in figure 7. It will be noted that the heaviest precipitation occurred over the eastern and southern parts of the watershed, and that the precipitation diminished in intensity toward the northwest. It is thought that this combination, which includes the July, 1909, storm, will give a greater annual run-off than has ever actually occurred from the watershed of the Wild Rice River in Minnesota. A comparison of figures 6 and 7 shows that the combined precipitation is heavier than that which occurred on the Wild Rice watershed in 1896, the year of maximum recorded annual precipitation over the Red River watershed.

In computing quantities for which storage and outlet capacities must be provided in order to control the run-off, it is necessary to take into account the amount of evaporation from the water surface of the reservoir. Using figures shown in Table 10, these quantities were computed in billions of cubic feet for an area of 35 square miles, the area of the exposed water surface at elevation 979. Any rise above this elevation would cause only slight increase in the surface exposed. These quantities were deducted from the estimated inflow to the reservoir.

A study of the relation of the run-off to rainfall in the watershed of the Wild Rice and the Mustinka, which latter is the principal tributary to Lake Traverse, indicated that the ratio was approximately the same for both watersheds.

Available data indicated that the run-off per square mile from the Lake Traverse watershed might be expected to be as large as may occur from the Wild Rice watershed and that the monthly distributions during the year would be nearly the same. The Lake Traverse watershed is 1.6 times as large as that of the Wild Rice. Accordingly, the run-off from the Wild Rice for the period January to June, 1916, and July to December, 1909, was increased by 60 per cent; and to make allowance for the earlier spring in the Lake Traverse watershed, one billion cubic feet was transferred from April to March. The monthly evaporation from Lake Traverse was then deducted and the remainder was taken as the maximum amount of water for which provision must be made. Monthly and accumulated quantities thus estimated are as follows, stated in units of billions of cubic feet.

| | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Monthly | 0.13 | 0.06 | 1.24 | 2.83 | 2.47 | 3.10 | 7.83 | 3.76 | 0.88 | 0.28 | 0.51 | 0.34 | 23.43 |
| Accumulated | .13 | 19 | 1.43 | 4.26 | 6.73 | 9.83 | 17.66 | 21.42 | 22.30 | 22.58 | 23.09 | 2.343 | ...... |

This run-off represents conditions that would obtain if, after a wet spring, a storm such as occurred in 1909 should cover the Lake Traverse watershed.

The relation between the precipitation and run-off for the storm of July, 1919, was investigated in the same manner. It was found that approximately the same percentage of run-off occurred from this storm as from the storm of 1909 on the Wild Rice watershed; but as would be expected, on account of the greater storm area and less intensive precipitation, the run-off extended over a longer period of time. Plans were then worked out to control a run-off from the Lake Traverse watershed of 23.43 billion cubic feet, which constitutes the total run-off for the hypothetical maximum year. It is equivalent to 25 per cent of the maximum annual precipitation recorded on the watershed.

### OPERATION OF THE RESERVOIR.

The reservoir is designed so to control the run-off from the tributary watershed that there will be no outflow from it in the spring before May 1 and, except under extraordinary conditions, the discharge through the sluiceway into the outlet channel will at no time exceed 1,000 second-feet. After May 1, such a flow can be accommodated by the river below without difficulty, except possibly at times of heavy storm run-off in the lower valley which may cause temporary high river stages. To relieve the lower channel under such conditions, the reservoir may be entirely closed for a period of at least 15 days at any time necessary, thus eliminating for such a period the flow from the Lake Traverse watershed.

The flow through the sluiceway, as planned, can be maintained at 1,000 second-feet under varying head, by regulating the gate opening, and at high reservoir stages over 2,000 second-feet can be discharged when necessary. It is proposed to place the spillway crest at elevation 983.0, which would give a storage capacity in the reservoir of 9.849 billion cubic feet when overflow begins. The spillway is planned to discharge at a rate of 2,000 second-feet when the water reaches elevation 985.0, which is 3 feet below the top of the dam. With the water at this elevation the reservoir would hold 12.035 billion cubic feet and the spillway alone would be discharging at a rate almost as great as the maximum rate of inflow which has been recorded. Table 15 gives the storage capacities of the reservoir at the different water surface elevations.

TABLE 15.—*Storage capacity for the proposed Lake Traverse detention reservoir south of White Rock, S. Dak.*

| Contours. | Areas within designated contours. | Mean areas=volumes when 1 foot deep. | Total storage capacity above elevation 972. | Contours. | Areas within designated contours. | Mean areas=volumes when 1 foot deep. | Total storage capacity above elevation 972. |
|---|---|---|---|---|---|---|---|
| | *Billions of sq. ft.* | *Billions of cu. ft.* | *Billions of cu. ft.* | | *Billions of sq. ft.* | *Billions of cu. ft.* | *Billions of cu ft.* |
| 972 | 0.610 | .......... | 0.000 | 980 | .996 | .986 | 6.764 |
| 973 | .680 | 0.645 | .645 | 981 | 1.017 | 1.007 | 7.771 |
| 974 | .749 | .715 | 1.360 | 982 | 1.037 | 1.027 | 8.798 |
| 975 | .811 | .780 | 2.140 | 983 | 1.065 | 1.051 | 9.849 |
| 976 | .873 | .842 | 2.982 | 984 | 1.092 | 1.079 | 10.928 |
| 977 | .915 | .894 | 3.876 | 985 | 1.121 | 1.107 | 12.035 |
| 978 | .956 | .936 | 4.812 | 986 | 1.149 | 1.135 | 13.170 |
| 979 | .976 | .966 | 5.778 | 990 | 1.243 | .......... | .......... |

The relations of inflow, storage, and outflow are shown in the mass diagrams of figure 20. It will be noted that, in these diagrams, the 15-day periods of no outflow have been taken in each case at a time when their effect in producing high reservoir stages would be greatest.

In diagram E of figure 20, the estimated mean annual run-off, "Inflow," was obtained by multiplying the mean monthly, 1909–1917, run-off of the Minnesota Wild Rice by 1.6, the ratio of the watershed areas, and deducting the loss by evaporation. The curve for the run-off of 1916, diagram A, figure 20, the year of maximum precipitation over the Lake Traverse watershed, was obtained by plotting as run-off for each month, 20 per cent of the precipitation over the watershed for the preceding month with the exception that 20 per cent of the total precipitation for December, 1915, and January and February, 1916, was plotted as the March, 1916, run-off, the January and February run-off being merely nominal. This ratio (20 per cent) of run-off to precipitation is the mean of those that prevailed immediately after the great storms on the Red River watershed as indicated by figure 19, and is considerably higher than is indicated for normal conditions by the rather meagre data available. Diagram E shows that with an outflow of 1,000 second-feet, starting May 1, the reservoir in a mean year would be brought to low stage by about the middle of June and that from that time on the outflow would at all times be less than 1,000 second-feet. The maximum storage required would be less than 2 billion cubic feet. In the case of run-off such as is estimated for 1916 (diagram A) all run-off prior to May 1 could be stored and the reservoir closed for 15 days during the summer, and yet the reservoir could be emptied by the middle of December. In that case there would be a maximum storage of 4.3 billion cubic feet, which would not raise the water above elevation 978.

In diagram B of figure 20, maximum spring run-off (January-June) was plotted in combination with the summer and fall run-off

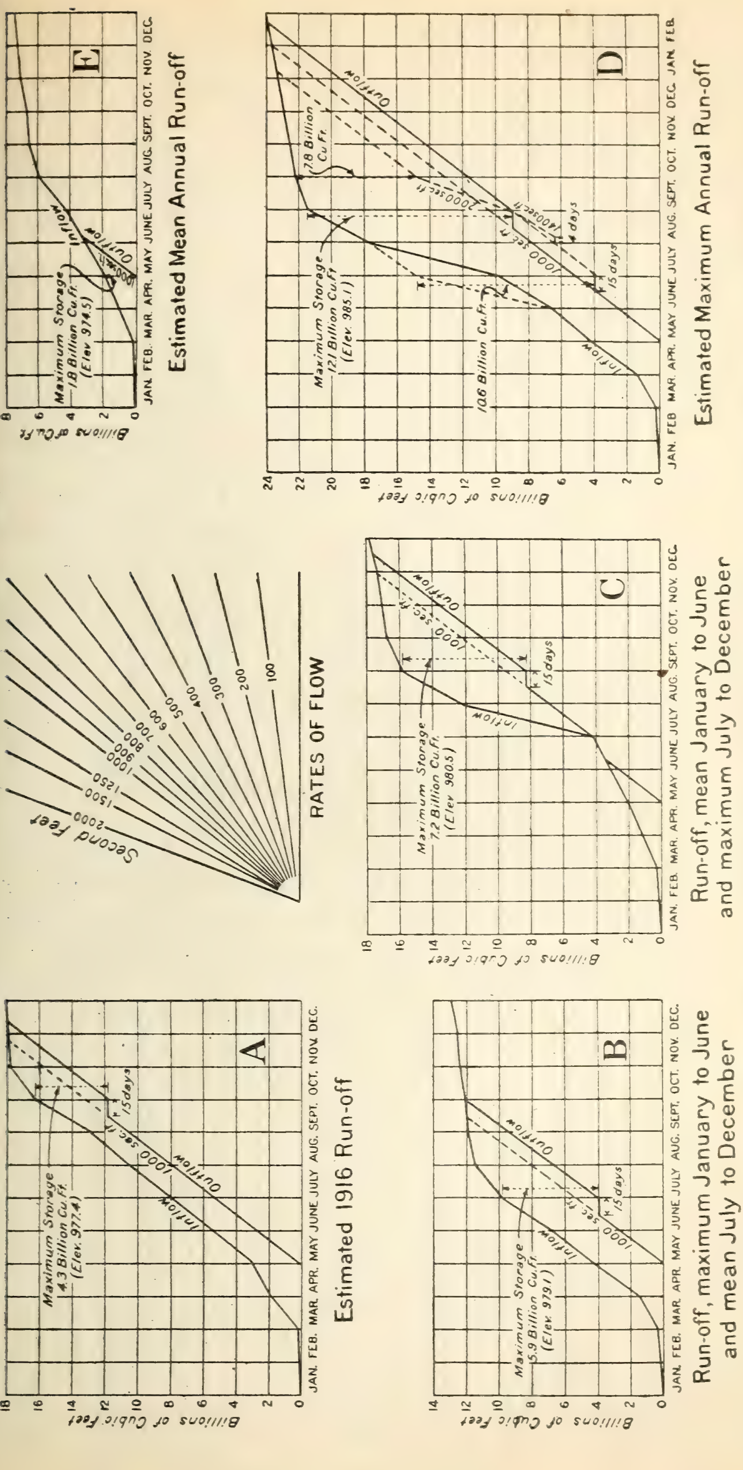


FIG. 20.—Relations between inflow, storage, and controlled outflow. Proposed Lake Traverse Detention Reservoir.

of the mean year. The maximum storage under these conditions is seen to be 5.9 billion cubic feet, at water elevation 979.1. The reservoir in this case would be empty by October 1.

In diagram C, figure 20, the run-off curve was made up of the spring run-off of the mean year (January-June) and the maximum summer and fall run-off (July-December). Maximum storage here is shown to be 7.2 billion cubic feet, at elevation 980.5. The reservoir would be empty by the middle of December.

In diagram D, figure 20, the most extreme conditions that may be expected are shown. The run-off plotted here is for the hypothetical maximum year as stated on page 64. This diagram shows that the maximum storage required in the most extreme case (that of closing the reservoir during the last 15 days of August) would be 12.1 billion cubic feet, if the rate of outflow were 1,000 second-feet continuously after May 1. However, before the water surface reached elevation 985.1 required for this amount of storage, the spillway alone would be discharging at a much greater rate than 1,000 second-feet, so that this stage would not be reached under these conditions and there would be a minimum freeboard on the dam of more than 3 feet. By regulating the outflow during September at 2,000 second-feet, which could be taken care of by the outlet channel if necessary, the storage could be reduced to 7.8 billion feet by October 1, and with a flow of 1,000 second-feet from then on the reservoir would be emptied by early in January. If the heavy July run-off were to occur in June, with that of June transferred to July, the maximum storage would be 10.6 billion cubic feet. If in addition to closing the reservoir for 15 days at one time it should become necessary, on account of some great storm, to close it at another time for a short period, say 4 days, an increase in the rate of outflow to 1,400 second-feet would in 10 days bring the storage back to normal. In all cases the reservoir would be empty before the heavy spring run-off of the following year begins. These conditions are extreme and in all probability never will occur; but should such a combination of run-off come, it can be controlled without damage to the reservoir and with less damage from flooding in the lower valley than would result from the unhampered flow of such run-off.

Should even worse conditions prevail than have here been considered, the reservoir would still be safe from destruction. The spillway and culvert together would be capable of discharging more than 4,000 second-feet when the water reaches elevation 985.0 in the reservoir. Before the water could rise high enough to overtop the reservoir the discharge through sluiceway and spillway would be more than doubled. To raise the reservoir to a height that would involve this rate of discharge would require a rate of run-off very much higher than has ever been recorded in the Red River watershed for an area as large as that draining to Lake Traverse. A discharge from the reservoir of 4,000 second-feet would flood the lands below the dam during the time that rate was maintained, and for a short time afterwards. It appears, however, that ample capacity with a safety factor for the most extreme conditions that will occur will be provided by the proposed works, and that the necessity for discharge at the rate of 4,000 second-feet would occur only at long intervals, if ever. The factor of safety in the case of the reservoir is somewhat higher than would be considered necessary in designing channels for the uncontrolled disposal of run-off. This is considered advisable in view of the cost of the reservoir, and the extent of damage to the controlling works which would follow failure of the dam, as well as the disastrous results in the valley below.

### THE OUTLET CHANNEL.

The location and courses of the proposed outlet channel are shown in figure 3, sheets 2, 3, and 4. Typical cross sections are shown in figure 4. As planned, the channel would follow the general course of the Bois de Sioux River with such cut-offs as are considered advantageous. It is possible to obtain a uniform slope of 0.0001 (about one-half foot per mile) for the entire length of 22½ miles. For the first 13 miles the proposed channel has a bottom width of 40 feet, widening out to 52 feet just above the entrance of lateral 1 of the secondary system (see fig. 3, sheets 2 and 3) and continuing thus for 4½ miles to the mouth of the Rabbit River where the bottom width again increases and continues at 80 feet to the end of the excavated channel, about 5½ miles south of Wahpeton. Side slopes of 1.1 are planned throughout. To obtain the necessary capacity in the Bois de Sioux channel between the end of the excavated channel and Wahpeton, it would be necessary to clear out the brush, trees, and debris, but no excavation is contemplated here. The sluiceway in the dam would discharge directly into the upper end of the outlet channel, and the spillway overflow would reach it just below through a short channel (see fig. 3, sheet 2).

The normal capacity of the upper 13 miles of the channel is 1,000 second-feet, increasing to 1,300 second-feet and 2,000 second-feet at the outlets of lateral 1 and Rabbit River, respectively, to provide for the additional flow entering at these points. A 10-foot depth of flow is sufficient to give these capacities, although a somewhat greater depth is available at all points below the outlet of lateral 1. To provide for extreme conditions it is planned to make the spoil banks on both sides continuous as far down as the outlet of lateral 1. This will permit a flow of 2,000 second-feet, which is 1,000 second-feet in excess of the normal capacity, without overflowing the adjoining land. The increased flow can be taken care of below this point by the greater width and excess of depth available as noted above. The continuous spoil banks would necessitate the use of flood gates for the small drains entering this section of the main channel, and the construction of spoil-bank levees along the lower parts of the larger ditches that enter the outlet channel. Such an arrangement would make possible the drainage of the low, wet areas along the Bois de Sioux, and only under the most extreme conditions of flow, which seldom occur, would there be any danger of flooding the lands adjacent to the outlet channel.

### THE SECONDARY DITCH SYSTEM.

The secondary ditch system is designed pirmarily to provide outlet for the local drainage which will be necessary in the development of the wet lands along the Bois de Sioux River. The ditches are placed also with the view of relieving the upper part of the main channel from the run-off from the adjacent land, leaving its entire capacity free for the removal of the discharge from the reservoir. The proposed locations of the seven laterals are shown on figure 3, sheets 2, 3, and 4. All would have final outlet into the main channel, with the exception of No. 7, which would discharge the water from Big Slough into the reservoir above the dam, thus permitting it to be controlled within the reservoir. These lateral drains are designed with capacities great enough to carry any probable run-off from their drainage areas and, because of construction limitations, are in most cases oversized.

### BRIDGES.

On account of the enlarged channel along the Bois de Sioux, it will be necessary to replace most of the present bridges with larger ones. Several of the steel spans can be used at their present locations by readjusting their elevations and constructing approaches, and some of the present pile trestles can be utilized as approaches for new steel spans at the same locations. As the design of highway bridges is in most States controlled by the State highway department, no consideration has been given to the design of the bridges necessary, but it is assumed that steel bridges with concrete abutments will be used. It is estimated that six spans 60 feet to 80 feet in length, and 14 spans 20 feet to 28 feet long, will be necessary.

### LOCAL DRAINAGE.

To gain full benefit from the proposed improvements, it will be necessary to supplement them by local drains in all parts of the affected areas. The secondary ditch system as planned herein will, to a certain extent, drain the land in the immediate vicinity of the ditches, but the main object of these ditches is to provide outlet for thorough drainage of small areas. Although a large amount of local drainage is necessary in the watershed, plans for it are not discussed here. This work should be taken up under State drainage laws.

### RESULTS OF IMPROVEMENTS.

Lake Traverse and the Bois de Sioux River constitute the outlet for 1,200,000 acres or 1,875 square miles of land, of which 1,345 square miles are in Minnesota, 170 square miles in North Dakota, and 360 square miles in South Dakota, as indicated in Table 1. Run-off from the higher parts, 1,087,630 acres, of this watershed now causes considerable flooding over an area of 112,370 acres of lower-lying lands divided among the three States as follows: Minnesota, 31,140 acres; North Dakota, 75,160 acres; South Dakota, 6,070 acres. This lower land is all directly tributary to Lake Traverse and the Bois de Sioux River below the location that has been suggested for the detention reservoir and dam.

The proposed improvements are designed to control the run-off from the upper watershed of 1,335 square miles above the proposed dam, (1) by storing in the reservoir all the run-off from this watershed during March and April; (2) by storing during other periods after May 1 the flow into the reservoir in excess of the 1,000 second-feet which would be discharged through the control outlet; (3) by storing all the run-off that occurs during any period of 15 days during the summer when the run-off from territory below the dam fills the channels farther down. The channel capacities and provision for control of run-off are so planned that when operating in conjunction with properly designed and constructed local drainage, the flow of water over the entire Lake Traverse-Bois de Sioux watershed can be so regulated that no serious damage will result from flooding or lack of drainage. As a result of the construction of the proposed improvements 112,370 acres will be protected from overflow and given good outlet drainage. The Lake Traverse-Bois de Sioux project is complete within itself. While it may, if desired, be included as a part of the larger Red River project, it can be prosecuted entirely independently of any other improvements.

### COST ESTIMATE.

A statement of the necessary construction work together with the estimated cost of the various items follows:

| | |
|---|---|
| Browns Valley levee and railroad embankment | $39,970 |
| Dam, earth embankment | 107,950 |
| Spillway | 66,960 |
| Control sluiceway | 67,960 |
| Approach to outlet | 25,700 |
| Main ditch | 394,770 |

| | |
|---|---|
| Secondary ditch system | $198,900 |
| Bridges | 89,260 |
| Flowage rights | 284,760 |
| Contingent expense (about 10 per cent) | 123,770 |
| Total | 1,400,000 |

This estimated cost, if raised by special benefit assessment placed on the 112,370 acres of land which would be affected directly by the improvements, would approximate $12.50 per acre. The assessment could of course be made less than that amount per acre by placing a part of the expense on the 1,087,630 acres of land which comprise the upper portion of the watershed. Some benefits would also accrue to the lands north of Wahpeton. It is impossible to estimate closely the probable cost to the various interests until the laws under which the improvements will be constructed are known. The cost of reclamation is, however, very reasonable when the value of the land as it now is and as it will be when drained is taken into consideration.

## RED LAKE—RED LAKE RIVER PROJECT.

The plans for improvements in Red Lake and Red Lake River as recommended in the report of the Corps of Engineers, United States Army (see House Doc. No. 61, 66th Cong., 1st sess.), contemplate the construction of a dam and sluices at the outlet of Red Lake for the control of lake stages and outflow, the building of rock jetties for the protection of the outflow channel, and the enlargement and straightening of the upper 45 miles of the Red Lake River channel. The construction of a lock for navigation is also considered but not recommended as necessary at this time. Certain features of the project are here described which are closely related to the larger Red River project described later.

### RED LAKE.

Red Lake has an area of 441 square miles. The adjacent land on the north, east, and west is low and flat with small streams and drainage ditches entering the lake. The land to the south is high and rolling and of a sandy character. During periods of high water the lowlands are overflowed and the drainage systems rendered inoperative. Commercial navigation is carried on to a limited extent in the lake which is of ample depth for the purpose. The approximate elevation of extreme high water is 1,177 and of extreme low water 1,173, giving a range of 4 feet.

It is proposed to limit the lake to a range of 3 feet by a control dam at the outlet, providing for minimum and maximum surface elevations of 1,171 and 1,174, respectively, for calm-water conditions, with an allowance for wind tide of 1 foot, bringing the extreme stage up to 1,175. The range of 3 feet will provide a storage capacity of 36,000,000,000 cubic feet, which will hold the estimated maximum annual flow of 25,000,000,000 cubic feet with a margin of 44 per cent.

### RED LAKE RIVER.

The Red Lake River has its source in Red Lake and has a length of 193 miles. It flows in a northwestery direction for 71 miles to Thief River Falls, thence in a southwesterly direction for about 61 miles, and thence in a northwesterly direction for about 61 miles to its junction with the Red River of the North at East Grand Forks, Minn.

For about the first 37 miles at the upper end there is no definite valley, the stream following a tortuous course through the flat, swampy country with its bed about 5 feet below the general land level. Owing to the slight fall the channel has been obstructed and filled in until it is inadequate to carry even the normal high-water discharges without overflowing the adjacent land. The valley takes form at High Landing; it is about one-eighth mile wide at Thief River Falls and the width increases to three-fourths of a mile at the mouth. Between Thief River Falls and Crookston the river descends in a series of short rapids. Below Crookston the fall decreases, giving depth and velocities of flow which permit navigation by small launches between Fisher and East Grand Forks. Below High Landing the banks are of sufficient height to prevent overflow under high-water conditions except on the lower portion just below Fisher (fig. 3, sheet 13), where at extreme high stages the river breaks over and a part of the flow discharges through the Grand Marais (fig. 3, sheet 14). There are but two tributary streams of importance, the Thief River entering from the north at Thief River Falls, and the Clearwater River entering from the east at Red Lake Falls.

### CONTROL OF RED LAKE.

The dam proposed for the control of the lake stage is of the ordinary type of reservoir dam adopted in that district, and consists of "a reinforced concrete floor resting on pile foundation, which in turn supports alternate piers and stop-log sluices." To prevent the refilling of the excavated outlet by littoral drift, it is proposed to construct jetties of loose bowlders extending about 1,600 feet out into the lake to the end of the excavated channel. The log sluice provided in the dam may be used for the passage of small launches between the river and lake. Tentative location for a regular lock was selected, should navigation ever warrant its construction.

### IMPROVEMENT OF RED LAKE RIVER.

As the extent of navigation does not warrant the expensive operations necessary to render navigable the stretch of river from Thief

River Falls to Crookston, and as damage from overflow and flooding occurs only above High Landing, channel improvement is recommenended only for the upper part of the river. It is proposed to deepen and widen the first 45 miles of the channel, straightening it by cut-offs at excessive bends, and thus reducing the actual length of the dredged channel to 40 miles. With a bottom width of 60 feet, side slopes of 1½ to 1, an 8-foot depth of flow, and a uniform slope of 0.7 foot per mile, the capacity is computed to be 1,037 cubic feet per second. This size and capacity is considered necessary to carry, with a minimum bank clearance of 2 feet, the maximum flow of 800 second-feet which may be expected under such conditions as occurred in the wet years of 1904 and 1905.

### RESULTS.

The most extensive benefits to be gained through this project will be in the improved flood and drainage conditions in the upper river, the lake, and the surrounding country. Next to this in importance is the advantage to water-power interests resulting from the controlled flow of Red Lake water. It is claimed that the project will be of benefit also to municipal water supply systems, and lastly that it will be of value to navigation in the lake and the upper reaches of the river.

### DRAINAGE AND FLOOD PREVENTION.

High stages in the lake and upper river cause great loss in the surrounding country by submerging considerable areas and backing up into the drainage systems. The lowering of the lake surface and improvement in the river channel will prevent flooding, eliminate the backwater which now obstructs flow in the present ditch systems, and make possible adequate outlet facilities for further drainage operations. Hundreds of thousands of acres of land, it is stated, will be benefited, some by reclamation from a state of permanent nonproductiveness, and some by transforming land—the farming of which is at best a hazard—into land upon which profitable returns are practically assured. According to documents No. 27, Sixty-first Congress, first session, and No. 971, Sixty-third Congress, second session, there are now or will be a total of 485,300 acres benefited by drainage systems tributary to Red Lake and Red Lake River above Kratka, Minn. Of this, 236,800 acres lie within the Red Lake Indian Reservation. The Army engineers' report assumes that the 485,000 acres may reasonably be assessed $1 per acre for benefit to be derived from the project.

### WATER POWER.

There are now in operation on Red Lake River four water-power plants having a total head of about 50 feet. The Army engineers estimate that the control works at the outlet of Red Lake would cause a minimum increase in flow of 500 cubic feet per second, which would make possible a total increase during low-water periods of about 2,275 horsepower for the four plants now in operation. At undeveloped power sites having a total head of 150 feet the increase would amount to about 6,825 horsepower.

### COST ESTIMATE.

The estimated cost of the proposed improvement as given in House document 61 is as follows:

| | |
|---|---|
| Channel excavation in Indian Reservation | $266, 457. 00 |
| Channel excavation in Pennington County | 300, 153. 00 |
| Jetties | 108, 300. 00 |
| Dam and auxiliaries | 52, 709. 20 |
| Administration | 12, 000. 00 |
| Contingencies | 39, 380. 80 |
| Total | 779, 000. 00 |

### APPORTIONMENT OF COSTS AND BENEFITS.

Following is an apportionment of the cost which is recommended by the report as equitably based upon the proportionate benefits received by the various interests:

| Interests. | Costs. | | Benefits. |
|---|---|---|---|
| | First cost. | Annual maintenance and operation. | |
| | | | *Per cent.* |
| Water powers | $240, 000. 00 | $3, 700. 00 | 30. 8 |
| Indian lands | 236, 800. 00 | 3, 650. 00 | 30. 4 |
| Lands outside Indian reservation | 248, 500. 00 | 3, 850. 00 | 32. 0 |
| Municipal water supply | 39, 000. 00 | 600. 00 | 5. 0 |
| Federal Government for navigation | 15, 000. 00 | 200. 00 | 1. 8 |
| Total | 779, 300. 00 | 12, 000. 00 | 100. 0 |

### ADMINISTRATION.

It is recommended in the report that the work of construction and operation be financed and accomplished through a drainage district organized under the laws of Minnesota, in cooperation with the Indian Bureau and under the supervision of the War Department, the Federal Government apportionment for navigation to be used to defray the expense of this supervision. The title to the works would be held by the drainage district, and all improvements made by the district would be in accordance with plans approved by the Chief of Engineers and the Secretary of War.

Preliminary proceedings are under way in several counties in Minnesota to organize a special improvement district to raise funds among the property owners for carrying on the work. The cooperation necessary between the Federal, State, and local authorities is not yet fully arranged.

The Red Lake-Red Lake River project is complete within itself and should be developed as a separate undertaking rather than as a part of the larger interstate Red River project. To attempt to combine the two projects would in all probability delay development in one or both without adding anything of value to either.

### THE EFFECT ON RED RIVER OF THE NORTH.

The proposed increase in minimum flow in the Red Lake River would increase to some extent the low-water stages of the Red River below the junction of the two streams and the control of Red Lake would decrease the high stages at Grand Forks by about 1 foot or possibly 1½ feet. The effect in lowering high stages of the Red River would be slight because the drainage area tributary to Red Lake is small as compared with that of the Red River above Grand Forks and because the relative effect of storage on high river stages decreases as the distance downstream from the reservoir increases. On account of the general distribution and more rapid concentration of heavy run-off in the spring, the effect of the control of Red Lake in lowering high stages of the Red River would be more consistently noticeable at this season than during storm periods in the summer months.

### RED RIVER PROJECT.

The problem presented by the Red River, considered alone, is essentially one of flood control. As an outlet for the drainage of the watershed it is capable, under ordinary conditions, of removing promptly the discharge of its various tributaries. It is only when excessive run-off occurs over all or a considerable part of the watershed that flood stages occur in the Red River. A relatively small reduction of the high stages would be sufficient to prevent overflow and the resulting damage. As there is no practicable method of entirely preventing the water from reaching the Red River in flood volumes, it is necessary that some plan be developed for controlling the flow within the channel.

There are four general methods of flood control or regulation which include practically all the devices employed for this purpose. These are the use of reservoirs, the construction of levees, stream diversion, and channel improvement. Often a combination of two or more of these methods may be necessary. In each of the methods there are a variety of plans, differing in details of design and construction by which the results may be accomplished.

### RESERVOIRS.

A study of the map of the valley and the profile of the river makes it apparent that the employment of reservoirs is not feasible along any part of Red River Channel and that this method of improvement may at once be eliminated. The flat, almost level topography extending from 10 to 30 miles back from the channel on both sides along its entire length offers no opportunity for the creation of a storage or detention basin at any point. To secure sufficient storage to affect flood stages appreciably it would be necessary during wet periods to inundate great areas of the most fertile land in the valley as well as farm homes and urban districts. This fact alone, without consideration of the practicability and expense of dams and other features necessary, precludes the pursuance of this plan in connection with the Red River proper.

On some streams it is possible to control floods by the use of reservoirs on tributary streams. The possibility of so controlling the floods on the Red River of the North was investigated. It was found possible completely to control the run-off from the Lake Traverse watershed of 1,335 square miles and from the Red Lake watershed of 1,950 square miles. The Otter Tail River above Fergus Falls, Minn., is now quite closely controlled by storage in natural lakes which act as reservoirs, and as the demand for power increases the run-off from this stream will no doubt be more closely controlled than it now is by the power companies.

The possibility of constructing storage reservoirs on other tributaries was investigated. It would no doubt be possible to construct reservoirs on some of the streams and completely control the floods on the watershed above the reservoirs, but the benefit from such control at this time was not found to be sufficient to warrant the expense. On the Sheyenne River, for instance, there are several locations where it appeared that dams might be constructed that would impound the run-off from the watershed above. Because of the light precipitation on the Sheyenne watershed the amount of run-off is seldom large when compared with that of the Red, and the effect on flood stages in the Red from cutting off the flood discharge from the Sheyenne would apparently be relatively small. The data in regard to run-off from the Sheyenne are meager and more are necessary to determine with some certainty the probable run-off. On other streams which have relatively high run-off from small watersheds, such as the Buffalo River, Wild Rice River, Snake River, and Two Rivers in Minnesota, no sites suitable for reservoirs which would impound a large quantity of water at a small cost were found. On the tributaries of the Red, coming in from the North Dakota side, somewhat similar conditions exist and in addition the rainfall is considerably lighter. As the valley develops and more complete protection from floods becomes necessary, the construction of reservoirs on some of the tributaries may be desirable.

## LEVEES.

The physical features of the Red River channel and valley are fairly well suited to the levee method of flood protection, and good results could be obtained by the proper location and construction of levees. However, there are several reasons for concluding that the adoption of this plan is not at present advisable, except possibly in certain reaches of the river.

To secure complete protection under all conditions, it would be necessary to construct levees from 5 feet to 20 feet in height along both sides of the greater part of the channel. In addition, it would be necessary to levee most of the tributary streams for considerable distances above their outlets. The enormous yardage of earthwork involved in such operations and the difficulty and expense of obtaining right of way, especially through the cities and towns, would run the cost high above that of other methods only slightly less effective.

It has been shown that, although floods may occur at any point along the Red River during the spring months, and although above the Sheyenne River the Red River may during the summer reach stages that are damaging to property within the outer high banks, it is altogether unlikely that any trouble from high-river stages will occur below the mouth of the Sheyenne except during March, April, and the early part of May. It is shown in the following paragraphs that by means of stream diversion and channel improvement the damage from summer flow above the mouth of the Sheyenne can be eliminated, and that the spring floods along the entire length of the river, except in the case of ice gorges, can be so reduced that no serious inundation of the adjacent land will occur. The overflows do not attain damaging velocities, and in spring they occur at a time when the only resulting damage to crops is a delay in the spring seeding. Moreover, with the increase in rates of flow, due to possible improvements in the channel, the water cover would be shallow, of short duration, and of rare occurrence; therefore it seems evident that the great expense involved in a complete levee system would not be warranted at the present time.

As the country becomes more thickly settled, conditions may make the construction of levees advisable along certain stretches of the channel where complete elimination of flooding is not to be secured by other means. In this connection it would be well if all buildings and other construction of a permanent nature could be kept at least 300 feet back from stream banks in order to provide the space necessary for the waterway and embankments should such construction be undertaken later. Furthermore, any local levee projects that may be taken up should be based upon some comprehensive plan in order that they may conform to possible future work of this nature.

### DIVERSION FROM DAKOTA WILD RICE RIVER.

There are numerous places in the watershed where stream diversion in one form or another can be advantageously employed. Of such cases there is but one, that of the Dakota Wild Rice River, where this method can be employed for directly effecting an improvement of flow conditions in the channel of the Red River, in conjunction with other measures recommended in this report. Projects of this kind which directly affect the tributary streams only, are not here considered except in a general way and should be taken up under the laws of the States in which the streams are situated.

As the Red River lies in the center of a broad valley flanked on both sides by land of considerable height, it is impracticable to divert any of the flow in the main stream to other outlets. Neither is it possible to divert the flow of any of its tributaries away from the Red, except in the case of Lake Traverse watershed and this plan has been rejected for sufficient reasons as a result of previous investigations. Auxiliary channels parallel with the river would be more expensive than the levee construction necessary to gain equal results, and are quite impracticable. The one remaining applicable plan in the way of stream diversion, is that of relieving overloaded sections of the channel by changing the locations of the outlets of tributary streams. Such changes in location are possible in various stream outlets along the river, but under present conditions and in view of results obtainable by channel improvements of the Red, the only such change that will produce results warranting the expense involved is a change in the location of outlet for a part of the discharge of the Dakota Wild Rice River during flood periods.

Recommendations in this connection contemplate a wide, comparatively shallow floodway with a capacity of 2,250 second-feet, leaving the channel of the Wild Rice River a short distance above the town of Wild Rice, N. Dak. (see fig. 3, sheets 7 and 8), following a northwesterly direction to the channel of the Sheyenne River, and entering the latter at some favorable point. The exact location of the floodway should be determined by a more detailed study of the locality than has yet been made. The length of the floodway would be about 7 miles. In addition it would be necessary to improve the channel of the Sheyenne River from the point where the floodway enters to the mouth of the river (see fig. 3, sheets 8 and 9), providing for a flow considerably in excess of that which it now can carry. This can be accomplished by clearing the channel of obstruction, no excavation being necessary.

The floodway should leave the Wild Rice River with a bottom elevation somewhat higher than the river bed, and should be provided with a concrete inlet sluiceway with control gates by which flow can be entirely closed off. By cutting the sides to a gentle slope the whole channel can be used for meadow or pasture land except during the short periods of a few days or weeks at rare intervals when it will contain water. Such use of the channel will be advantageous not only agriculturally but also as a means of channel maintenance.

The portion of the Red River channel between the mouths of the Dakota Wild Rice and Sheyenne Rivers is rather restricted and badly obstructed in certain parts. Above Fargo it is somewhat larger than below but owing to greater obstruction has about the same capacity of flow. At present about 6,000 second-feet is the maximum flow that can be accommodated without overflow of improved property. By channel improvement this can be increased to 8,000 second-feet from the mouth of the Wild Rice to Fargo, and to 7,500 second-feet from Fargo to the mouth of the Sheyenne. Of course the smaller figure governs in the design for relief (see fig. 3, sheets 7 to 9, inclusive).

The rate of flow in this part of the river channel has exceeded 7,500 second-feet in the past, and without doubt will do so in the future unless steps are taken to control it. It is proposed here, by diverting part of the flow of the Dakota Wild Rice River and by controlling the run-off from the Lake Traverse watershed, to limit the flow in this portion of the channel of the Red River to a maximum of 7,500 second-feet, which can be carried by the improved channel without damage to contiguous property. As the outlet of the Wild Rice into Red River is but a short distance above Fargo, a large reduction in rate of discharge from Wild Rice will result in practically equal reduction in rate of flow in the Red River at Fargo and just below that point, where the channel capacity is restricted.

Considering first the summer flood flow (see Table 5), this is estimated at a maximum of 9,652 second-feet at Fargo; the probable maximum for the Wild Rice is 3,315 second-feet; for the Red above the mouth of the Wild Rice, 6,656 second-feet; and for the small streams between this point and Fargo, 520 second-feet. Assuming that when the flow at Fargo reaches the maximum of 9,652 second-feet the Wild Rice is contributing its maximum of 3,315 second-feet, the flow at Fargo can be reduced to less than the allowable 7,500 by diverting 2,250 second-feet from the Wild Rice through the floodway. On the other hand, if the Red River above the mouth of the Wild Rice, and the small streams between that point and Fargo, were all flowing at their maximum rates, the Wild Rice would be contributing only 2,476 second-feet, and by diverting 2,250 of this through the floodway the flow at Fargo would be kept within the safe limit. In any case, when the flow at Fargo would amount to 9,652 second-feet without control, enough could be diverted through the floodway to reduce it below 7,500 second-feet without overtaxing the diversion channel. With the stage in the Red high enough to cause a flow of 7,500 second-feet at Fargo, the stage in the Wild Rice at the entrance to the floodway would be high enough, either from the flow of the Wild Rice itself or by backwater from the Red, to allow the withdrawal of the 2,250 second-feet at an elevation considerably above the bed of the Wild Rice.

The probable maximum spring flood flow at Fargo, amounting to 11,580 second-feet, is next considered. To produce such a flow would require that all the tributaries above this point should reach very nearly the maximum spring flow as noted in Table 5, and that each should crest at such particular time as would produce the maximum combined effect at Fargo. Although it is not believed that such a condition will ever exist in the case of summer floods, it is possible that it will occur in the spring. In this event the flow in the Wild Rice River would be 4,420 second-feet. By diverting 2,250 second-feet through the flood way, the flow of the Red at Fargo would be reduced by practically that amount. Assuming that the effect of the 2,670 second-feet flowing from the Lake Traverse watershed is reduced to 30 per cent before reaching Fargo, which under conditions of flood flow is considered liberal, it is seen that by closing the sluiceway at the Lake Traverse detention reservoir and completely shutting off this flow during the spring months the flow at Fargo from this source would be reduced by 1,870 second-feet. This, combined with a reduction of 2,250 second-feet caused by diversion of this amount from the Wild Rice River, would give a total decrease of flow at Fargo of 4,120 second-feet, which would bring the flow at this point well within 7,500 second-feet. With such control of the flow in operation and the recommended channel improvements described hereafter accomplished, the elevation of the flow line during such floods as that which occurred in 1897 would be lowered about 15 feet.

The surveys and investigation make it apparent that the overflow, during flood periods, of the land along the west side of the Red River where the Wild Rice and Sheyenne Rivers flow almost parallel with it, are not caused entirely by overflow from the Red. Both of these tributaries have channels of insufficient capacity to carry their flood flow and are partly responsible for the floods in this region. Consequently it will be necessary, in addition to providing a diversion channel for the Wild Rice, to improve the channels of the Wild Rice and Sheyenne Rivers above the points where the floodway joins them. While this probably can be more readily accomplished under the laws of North Dakota, it should be done at the same time and in cooperation with the floodway project. The floodway would so relieve high-water flow in the Wild Rice below the intake that little or no work on the channel would be necessary below this point. The improvement of the Sheyenne channel below the outlet of the floodway would necessarily be included as a part of the Red River project.

### CHANNEL IMPROVEMENT IN RED RIVER.

In considering possible methods for improving the channel of the Red River, two may at once be discarded as impracticable, taken either separately or in combination. These are cut-offs, and enlargement of the present channel. The number of cut-offs to be made, the great size of the excavated channel required, the depth of cutting necessary, and the disposal of the immense quantities of excavated material, require a scope of operations and present technical difficulties that would make the cost prohibitive.

The most economical plan in this connection, and a very effective one, is that of clearing the channel of the obstructions which greatly retard the flow and are in a large measure responsible for overflow during high-water periods. As previously noted, the channel throughout its length is more or less obstructed by trees, brush and undergrowth, artificial structures, refuse dumps, and débris of various kinds. Along certain reaches the channel is almost completely choked by trees with the exception of a narrow strip which serves as a low-water channel and is kept open by the continuous flow throughout the year. During high-water periods the entire channel is necessary to carry the flow and, as a result of the obstructed condition of the greater part of its cross-sectional area, the velocities are so low that the water passes through the channel at a slower rate than it is brought in by the tributaries. Such channel conditions also tend to cause serious clogging by floating ice when it is present.

It is recommended that from Wahpeton, N. Dak., to the Canadian boundary, a distance of 394 miles along the river (see fig. 3, sheets 4 to 20, inclusive), the channel be cleared of all trees, brush, deadfall, débris, and structures of all kinds except bridges, which seriously interfere with the free flow of water. If possible the entire high-water channel should be cleared. The channel, having once been cleared, should be maintained permanently in good condition. This can best be done by pasturing the channel, or using it for hay land. It is not believed advisable to include under this project the removal and rebuilding of all bridges which cause obstruction to flow, as most of these are of wood and will not be serviceable for more than a few years, after which they must be replaced or the crossings abandoned. In replacing present bridges and in constructing additional ones, it should be required that all bridges shall span the whole channel and be placed high enough to clear the high-water flow.

The width of the channel to be cleared varies in different sections of the river and the amount can be determined only by a detailed survey. An approximation of average widths for three sections of the channel based on information secured during the survey gives the following: From Wahpeton to Fargo, 100 feet on each side of the present low-water or open channel; Fargo to Grand Forks, 150 feet on each side; Grand Forks to the Canadian boundary, 200 feet on each side (see fig. 4). With such a strip cleared on each bank the approximate average widths of open channel in the three sections mentioned above would be 300 feet, 430 feet, and 600 feet respectively. As a result, during high-water periods the volumes of water which would pass in a given time through this wide unobstructed channel would greatly exceed those under present conditions.

It is believed advisable to gain control, under this project, of a strip of land 200 feet wide outside the land actually to be cleared on both sides. This would provide ample space for operations and for limiting all encroachments. After clearing the channel, the part of it outside the low-water flow-line should, where possible, be seeded to grasses; this would not only provide pasturage or hay land, but also would aid in keeping down the cost of maintenance.

### EFFECT OF CHANNEL CLEARING.

The value of channel clearing becomes more evident when the results are reduced to figures which show approximately the increase in carrying capacity of the channel that can thus be secured. The section between Wahpeton and the mouth of the North Dakota Wild Rice River at present will carry about 4,000 second-feet without overflow. By the proposed clearing this can be increased to 5,400 second-feet, which with the reduction in flood volumes obtainable through the Lake Traverse detention reservoir will be adequate to provide for the disposal of all spring and summer flow. From the mouth of the North Dakota Wild Rice to the mouth of the Sheyenne the capacity can be increased from 6,000 second-feet, its present value, to 7,500 second-feet. Between the mouths of the Sheyenne and the Red Lake Rivers, the capacity of the Red River channel is now 15,000 second-feet and this can be increased by about 3,500 second-feet which would be ample to prevent practically all overflow along that section of the stream. Below the mouth of the Red Lake River at Grand Forks the channel in its present condition will carry 25,000 second-feet; by clearing out obstructions a flow of 30,800 feet can be provided for throughout the remainder of its length in the United States. The increase in capacity securable amounts to from 20 per cent in the larger part of the channel below Grand Forks to 35 per cent just below Wahpeton where the sectional area is much smaller. The construction of the improvement on Red Lake and Red Lake River will also have some effect in reducing flood stages below Grand Forks. On account of the considerable distance the water must travel to reach the river after leaving Red Lake, the effect of reducing the flow from that lake will be partly lost before Grand Forks is reached. These capacities indicate the rates of flow that can be accommodated throughout the length of each section without overflow at any point.

The increased capacity thus gained would not entirely eliminate flooding below the mouth of the Sheyenne River. The rates of flow provided for—18,500 second-feet below the mouth of Buffalo River and 30,800 second-feet below the mouth of Red Lake River—probably will be exceeded in the spring at intervals of from 10 to 25 years, during such floods as occurred in 1882 and 1897. It is possible that at still rarer intervals the summer flow may cause slight flooding, but it is highly improbable that this will occur, because overflow during the summer could only be caused by run-off about 40 per cent greater than has ever been recorded at that time of the year.

In all cases of flooding the river stages would, as a result of the improvements, be lowered by approximately 5 feet; this would reduce the flood damage to a point where further reduction would not be economical at present.

### RESULTS OF IMPROVEMENTS ALONG THE RED RIVER.

The works recommended along the Red River between Wahpeton, N. Dak., and the Canadian line consist of: (1) A floodway connecting the Dakota Wild Rice and Sheyenne Rivers at some distance above their mouths; (2) the improvement of the Sheyenne channel below the floodway outlet; and (3) the clearing out of the Red River channel for a distance of 394 miles from Wahpeton to the Canadian boundary. The maintenance of these works when once constructed is essential to the success of the project.

The results of these improvements may be summed up as follows:

From Wahpeton to the mouth of the Dakota Wild Rice River the capacity of the Red River channel would be great enough to provide for any volume of water that will come, provided the recommended Lake Traverse storage reservoir is in operation; thus overflow along this section of the river would be eliminated.

The floodway channel from the Dakota Wild Rice to the Sheyenne River, functioning in conjunction with the Lake Traverse reservoir, would so control the flow in the restricted section of the Red River channel between the mouths of the Wild Rice and the Sheyenne that it would at no time exceed the rate of 7,500 second-feet, which can be carried without overflow through that section of the channel when cleared of obstructions as recommended. Overflow of the Wild Rice and Sheyenne channels, below the points where the floodway joins them, would also be eliminated. Overflow of these channels above the floodway can be eliminated by proper channel improvements carried out under local authority in conjunction with the Red River project.

The capacity of the Red River channel below the mouth of the Sheyenne River would be increased to such an extent that only the greatest floods of rare occurrence would cause overflow, and in these the river-stages would be lowered 5 feet below the elevation they reach during similar floods under present conditions. Owing to this lowering of the river-stages and the greater rapidity with which the flood volumes would be disposed of, the extent, depth, and duration of inundation would be greatly reduced. The resulting damage would thus be reduced and the quick return to normal conditions would prevent serious delay to farming operations.

In short, if these improvements were properly effected and maintained all flooding along the Red River would be eliminated except for slight overflow below the mouth of the Sheyenne River on rare occasions under the most extreme conditions, and such overflow as may occur there would not cause serious damage.

In order that these results shall extend entirely to the Canadian boundary it will be necessary that the channel improvements be carried some 30 miles beyond the boundary. Otherwise, the sudden change from the open, unobstructed state of the channel to the choked condition which now obtains below the line, would cause the flooding of territory near the boundary both in the United States and in Canada. Some arrangement should be made with the Dominion of Canada whereby the channel improvement may be continued far enough to prevent such an occurrence.

## ESTIMATES OF COST.

The estimated cost of the improvements along the Red River between Wahpeton, N. Dak., and the Canadian boundary follows:

| | |
|---|---|
| Flood way (including concrete inlet) | $355, 000 |
| Improvement of Sheyenne River channel below the flood way | 95, 000 |
| Improvement of Red River channel from Wahpeton to the Canadian boundary | 3, 300, 000 |
| Total in United States | 3, 750, 000 |
| Additional for work in Canada | 250, 000 |
| Total | 4, 000, 000 |

These estimates were prepared during 1920 and it is probable that by the time the organization is completed the costs of making the improvements will be somewhat less.

The Red River overflows damage 500,000 acres of land within the limits of this project. The improvements proposed therefore would afford the protection, as stated above, for an average cost of $8 per acre.

## ORGANIZATION.

In the three States interested in these projects, as in most other States, action to secure drainage improvements to be paid for by special assessment must be initiated by a petition from owners of land that will be affected. The drainage laws of Minnesota, North Dakota, and South Dakota were passed for the same purposes, but they vary considerably in the organization effected for carrying on the work and in the details of procedure. The drainage and conservancy act of Minnesota was passed in 1919, and provides for large districts and confers upon a board of directors the necessary powers to construct such improvements as may be necessary to drain the land and to prevent overflow. In North Dakota and South Dakota action will probably have to be taken under the general drainage laws. These work satisfactorily where only one county in the State is interested, but the organization becomes rather cumbersome when a large number of counties are included. Under all of the laws it would apparently be necessary for the organizations in the different States to enter into an agreement among themselves in regard to the distribution of the cost of the work and the organization which would have charge of the construction. If satisfactory results are to be secured on projects of the magnitude of Lake Traverse-Bois de Sioux and the Red River of the North, it is essential that control of the project be definitely centralized both during the construction and afterwards for the purpose of maintenance.

One way in which the work could be handled would be for each State to organize the lands within its boundaries which will be benefited as a drainage district. The administrative officials of each district could then meet as one board which would have entire charge of the project as a whole. It would be the duty of this board to have the benefits apportioned to the lands in the district, to let contracts for constructing the improvements, and to arrange for necessary funds. After the benefits had been apportioned and the contracts let, proportionate parts of the cost could be certified to the district interested in each State and they could spread the cost over the benefited lands within their boundaries.

In the event that this method of carrying out the work proved difficult of operation or unsatisfactory it might be possible to have the legislatures of the several States interested enact legislation providing for the appointment of members of a joint commission which could be given the authority granted to commissioners of drainage districts. An organization formed along the lines of that provided by the Ohio conservancy act should be able to carry on the work effectively and economically. If it is necessary to make provision for a special board or commission, care should be taken to see that the number of members is not too large.

Practically all streams, even the smallest, affect areas that extend beyond the control of any one interest; and as the effects upon any part of the lands through which they flow are not due to causes originating wholly within that part but to broadly distributed conditions these streams should, to an extent, be considered as public property. The conditions along a stream are the result of natural processes not confined to any locality, and the beneficial effects of streams, as well as the extent of damage due to their existence, are dependent upon the balance of affecting conditions throughout the watershed.

These conditions can be controlled to a great extent by artificial means and the natural processes so directed as to operate to the lasting benefit of mankind. As the development of any part of a watershed may affect other parts, it is most desirable that there should be some central authority over the whole, to regulate such developments so as to receive the most equitable distribution of benefits among all concerned.

Such authority is desirable not only in regulating the construction and maintenance of artificial development, but also in preventing deterioration of the natural waterways as they exist. All artificial works require inspection and repair from time to time to keep them in proper order, and all channels whether natural or artificial are subject to a variety of conditions which impair their usefulness.

Little attention to proper maintenance of watercourse channels, as such, has been given in the past and much damage has resulted from channel obstruction and ungoverned flow, where the only reason for such damage was the lack of authority and initiative to remedy the evil. The need of such authority is generally understood and admitted, but until some definite action is taken in the matter present conditions will continue. Legislative action regarding this should not only provide the necessary authority, but should also impose the responsibility for administering it, and fix penalties for failing to do so.

## CONCLUSIONS.

Owing to peculiar topography, soil, and climatic conditions much of the land in the Red River drainage basin requires extensive artificial drainage although in many respects it is naturally well adapted for farming. Much has been accomplished in the way of reclamation of swamp lands and the improvement of run-off conditions, but further operations are necessary to provide adequate outlets and to relieve overflow conditions, especially along the Red River. The danger of overflows makes the farming of large areas impossible or hazardous; also it interferes with urban activities and with transportation. These unfavorable conditions can be eliminated by carrying out the improvements as recommended.

The organization of these projects will require considerable time. Delays increase the probability that additional damage will be caused by floods. It is desirable therefore that action which will result in permanent organizations be started as early as may be possible. Coordinated effort on the part of the interested States and the Federal Government in the collection of data in regard to precipitation and run-off in the three States will result in securing much information of value for preparing detail plans for the work and for operation after the improvements are completed.

## RECOMMENDED INTERSTATE PROJECTS.

Two interstate projects are recommended, each to be handled either by an executive board made up of district officials from each State or else a commission appointed for the purpose which would have full authority.

The tri-State Lake Traverse-Bois de Sioux project would include land in six counties, as follows: Roberts County, S. Dak.; Richland and Cass Counties, N. Dak.; and Traverse, Wilkins, and Clay Counties, Minn. The Red River project would include land in 12 counties, viz, Wilkin, Clay, Norman, Polk, Marshall, and Kittson Counties, Minn.; and Richland, Cass, Traill, Grand Forks, Walsh, and Pembina Counties, N. Dak. It is recommended that the two projects include all the territory along Lake Traverse, Bois de Sioux, and the Red River.

In controlling run-off and stream-flow various interests such as land drainage, flood prevention, water power, navigation, and others sometimes overlap and conflict. In the two projects proposed herein no serious conflict is foreseen. Should any question as to priority of interest develop it is believed that land drainage and flood prevention will be recognized as of much greater importance than any other interests here involved.

## BENEFITS AND COSTS.

Damages from floods and lack of drainage on large areas can only be approximated. It is conceded generally that large losses from these causes have been sustained in the Red River Valley. According to conservative estimates the loss due to the 1897 flood alone was over $7,000,000. As the value and amount of property in the valley is constantly increasing the danger of much greater losses from floods and lack of drainage is increasing also. At present a flood equal to or greater than that of 1897 would cause much more damage than was caused by that flood. By improving the river channel as proposed, flood heights could be reduced by 5 feet or more and additional outlet facilities needed in some localities would be provided.

Benefits which would accrue from improved drainage outlets such as are proposed in the Lake Traverse-Bois de Sioux project would add greatly to the value of the land affected.

It appears, therefore, that the two projects are well worthy of adoption. The benefits that would be secured during future periods when large run-off occurs, such as now causes floods, will be large enough to warrant a considerably greater expenditure than will be necessary to obtain relief from these conditions.

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